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ECOLOGY OF SPHAEROTILUS IN ACTIVATED SLUDGE

Wesley O. Pipes

Northwestern University
Evanston, Illinois

December 1967

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THIRD ANNUAL REPORT

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ECOLOGY OF *Sphaerotilus* IN ACTIVATED SLUDGE

THIRD ANNUAL REPORT

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December 1967

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Details of illustrations in
this document may be better
studied on microfiche.

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INTRODUCTION

The activated sludge process is generally accepted as being the most effective method of biological waste treatment when operated properly. It is possible to obtain an effluent from an activated sludge process which is comparable in quality to the water flowing in many natural watercourses. However, it is also generally accepted that a particular activated sludge process may be quite easily upset and likely to produce poor results from time to time. It is even possible to obtain an effluent from an activated sludge process which is of lower quality than the waste being treated. Thus, the effectiveness of an activated sludge process depends entirely upon how well it is operated.

Since the inception of the activated sludge process, operating problems have been associated with the growth of excessive numbers of filamentous organisms in the sludge. Filamentous organisms are believed to interfer with development of an activated sludge with proper settling characteristics. Since separation of the activated sludge from the effluent by sedimentation is absolutely essential for obtaining proper operation of the process, anything which interfers with the settling of the sludge produces a serious operating problem.

Any problem with separation of activated sludge in the secondary settling tank, particularly if large concentrations of sludge solids are being lost into the effluent, may be called "bulking." There are several descriptions of bulking sludge in the literature of waste treatment and some of these differ greatly in particular points of the descriptions. Most of the literature descriptions of bulking ascribe its cause to an overgrowth of a particular filamentous organism, Sphaerotilus natans, in the sludge.

A literature review (1) published as a result of work on this project demonstrated that in the past a number of different phenomena which may occur in an activated sludge process have been included under the general name of bulking. The inclusion of these various phenomena under one name has resulted in a great deal of confusion about the cause of and possible cures for many operational problems of the activated sludge process.

The objective of this research project is to provide data which will serve as a basis for quantitative description of some of the phenomena which produce an activated sludge which separated poorly, to determine which filamentous organisms are associated with which phenomena, and to identify environmental factors in the process which could cause the occurrence of each phenomenon.

The general plan of this research project is to obtain samples from operating activated sludge processes in full scale waste treatment plants, to determine if a sludge separation problem exists, to identify the filamentous organisms present, and to provide some description of the environment of the process. Sampling trips are made to waste treatment plants on a schedule which will allow a total of 63 trips over a two year

period. Fifteen different activated sludge processes will be sampled four times each and three processes already sampled once will not be sampled further. This report covers the results obtained from the first thirty sampling trips.

Theoretical Framework

The particular theoretical concepts upon which this project is based depends primarily upon the idea that the objective of the activated sludge process is to develop a biological sludge which is able to convert organic matter suspended and dissolved in a waste water into a settlable form. As a general rule, most operating problems with the activated sludge process are manifest first as problems of separating sludge from the effluent by sedimentation.

Separation of sludge in the secondary settling tank depends not only upon the settling and compaction characteristics of the sludge itself, but also upon the design and operation of the settling tank. Design deficiencies which can result in poor separation of a sludge with good settling characteristics include inadequate volume, inadequate surface area, an inlet structure which does not properly dissipate the hydraulic energy of flow into the tank, poor tank geometry which produces density currents and dead spaces in the tank, inadequate or improperly located outlet structure, and a sludge removal mechanism which resuspends sludge which had settled. In a project of this type, it is necessary to determine if the separation problem is a result of design deficiencies in the settling tank or of poor settling characteristics of the sludge itself.

Even a sludge with optimum settling and compaction characteristics can be lost from a well-designed settling tank if the tank is operated poorly. The most common deficiency of operation of the secondary settling tank is allowing excessive accumulation of sludge in the tank. If the rate of sludge removal from the secondary settling tank is less than the rate of sludge influx, sludge will accumulate in the settling tank. It is possible, under certain conditions, for the entire volume of the settling tank to be filled with sludge, resulting in sludge loss into the effluent. However, it is more common for the accumulated sludge to become anaerobic in the bottom of the tank, produce small bubbles due to denitrification or fermentation, and then to rise to the surface.

If an activated sludge process has a well-designed and well-operated secondary settling tank, any loss of sludge into the effluent is a result of poor settling or compacting characteristics of the sludge. The settling and compaction characteristics of the sludge are the result of the nature and amount of inert solids in the sludge, the biological population of the sludge, and the form of growth of the biological population. However, environmental factors in the secondary settling tank influence the expression of the settling and compaction characteristics (2,3).

The inert material in the sludge includes suspended material originally present in the influent waste and extracellular material secreted by the organisms growing in the sludge. The organisms present in the sludge are determined by the nature of the waste being treated, the

environmental conditions in the process, and the outcome of biological competitions between the sludge organisms. Many of the microorganisms of activated sludge can grow in different forms; e.g., as single cells, flocculated masses, or filaments. The same influences which determine the organisms present will also determine the form of growth of the organisms.

This theoretical framework can be summarized by a series of statements. Obtaining good results from an activated sludge process depends directly upon obtaining good separation of sludge in the secondary settling tank. Poor separation of sludge can be the result of poor design or poor operation of the secondary settling tank or of production of sludge with poor settling or compaction characteristics. The settling and compaction characteristics of the sludge are the result of the inert material present, the organisms present, and the form of growth of the organisms. The inert material, the organisms and their form of growth are controlled by the nature of the waste being treated and the environmental conditions in the process.

Hypotheses

In a project of this type, it is not possible to verify the entire theoretical framework for the proper operation of an activated sludge process. However, certain parts of the theory can be broken down into hypotheses and the individual hypotheses tested against the data collected. The data presented in this report are arranged so that they relate to the following hypotheses:

1. The BOD of an effluent from an activated sludge process is primarily a function of the amount of sludge lost from the secondary settling tank.
2. A severly bulking sludge entraps small particles as it compacts and thus produces a very clear supernatent.
3. Factors other than particle size control the settling and compaction rates of activated sludge.
4. The SVI of a sludge sample is proportional to the number of filaments per gram of sludge.
5. A number of different filamentous organisms may or may not be present in sludge having a high SVI.
6. Many of the filamentous organisms associated with bulking are present in normal activated sludge.
7. Excessive growth of Bacillus cereus, B. cereus var. mycoides, Sphaerotilus natans, and a few other filamentous bacteria in activated sludge can cause the development of severe bulking condition.
8. In the absence of excessive numbers of filamentous bacteria, the SVI of a sludge sample is proportional to the number of yeasts present.
9. When deflocculated sludge is produced, the sludge which settles often has an SVI in the range 100 to 200 ml/gm.
10. Pin point floc occurs only when a sludge having a very low SVI is produced.

PLANT DESCRIPTIONS

Fifteen activated sludge plants were selected for inclusion in the sampling program. These plants were selected with the objective of including a variety of types of activated sludge processes and finding plants which had a history of operational problems. Three plants with no history of operational problems were also selected for purposes of comparison. However, this sample can not be considered as a representative or even a random sample of activated sludge processes. A number of plants were rejected because they were not likely to produce examples of operational problems.

The fifteen plants included in the sampling program will each be sampled four times during 1966-1968. The four sampling trips for each plant will be distributed over the four seasons of the year.

Three plants which will not be sampled further were each sampled once during the first month of the project. These plants were rejected from the fifteen plant samples because of planned construction and lack of readily available data about plant operations.

The plant descriptions and operating data in this section were obtained from personnel responsible for plant operations. They represent nominal operating conditions and are presented to give an idea of the types of plants sampled.

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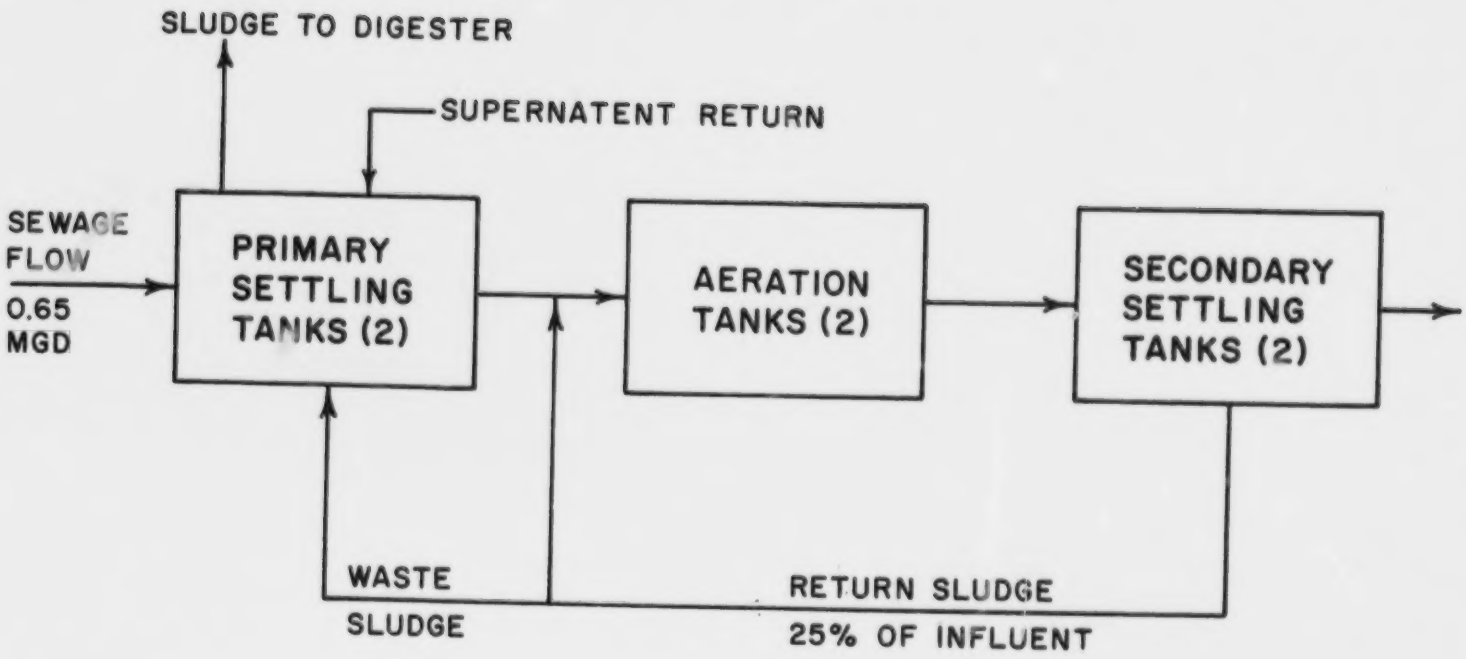

FIG. I - SCHEMATIC FLOW DIAGRAM OF CAROL STREAM TREATMENT PLANT

1. Identification

   a. Location: Carol Stream, Illinois
   b. Responsible Agency: Carol Stream Utilities Co.
   c. Information obtained from: Al B. Shimas, Utilities Manager

2. Wastes Treated

   a. Total Flow: 0.65 MGD
   b. Industrial Wastes: Printing Plant - ink and solvents

3. Pretreatment

   Screening and Grit Removal

4. Primary Treatment

   Two primary settling tanks, rectangular, horizontal flow

5. Activated Sludge Process (Conventional)

   a. Two aeration tanks operated in parallel
   b. Total Volume: 87,500 gallons
   c. Detention Time: 3.42 hours
   d. Mechanical aeration
   e. Two secondary settling tanks
   f. Return Sludge Rate: 175,000 gallons per day
   g. Sludge wasted to primary as needed

6. Sludge Disposal

   Anaerobic digestion and burial of digested sludge

7. Operational History

   Plant has been badly overloaded for several years. Produces a finely divided sludge which settles very poorly.

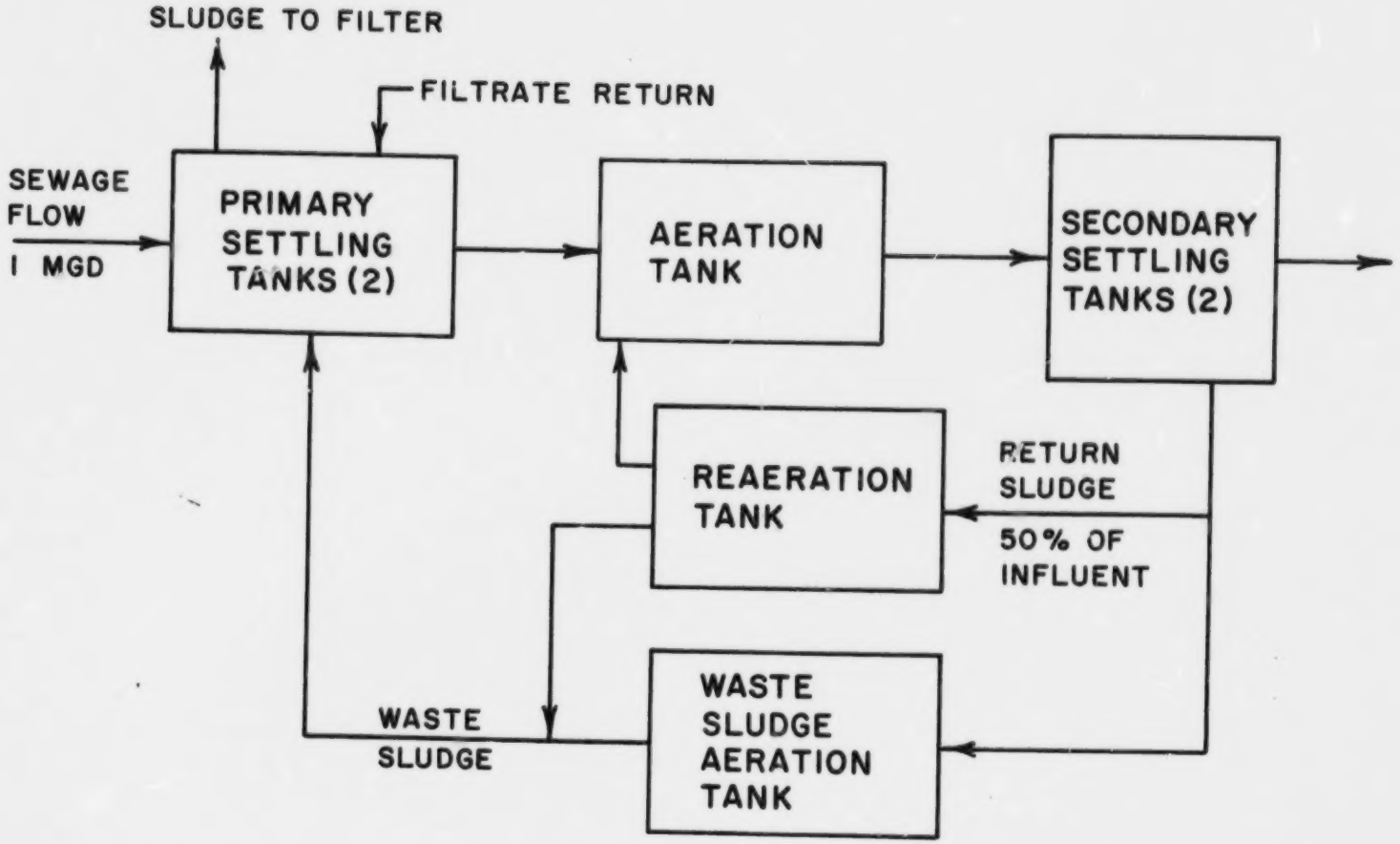

FIG. 2 - SCHEMATIC FLOW DIAGRAM OF TREATMENT WORKS AT WEST CHICAGO, ILLINOIS

1. Identification

   a. Plant Location: West Chicago, Illinois
   b. Responsible Agency: City of West Chicago
   c. Information obtained from: Robert McFarland, Chief Operator

2. Wastes Treated

   a. Total Flow: 1 MGD
   B. Industrial Wastes: Bakery, Pickle Factory

3. Pretreatment

   Screening, grit removal, and preaeration

4. Primary Treatment

   a. Two primary settling tanks, rectangular, horizontal flow
   b. Total Volume: 76,000 gallons
   c. Detention Time: 1.82 hours
   d. Surface Area: 1260 ft^2
   e. Overflow Rate: 795 gpd/ft^2

5. Activated Sludge Process (Contact Aeration)

   a. One contact tank 173,000 gallons, one reaeration tank, 154,000 gallons
   b. Total Volume: 327,000 gallons
   c. Detention Time: 7.9 hours
   d. Diffused air capacity: 2900 cfm
   e. Air Supply Rate: 3 ft^3/gal
   f. Three secondary settling tanks, two square, upflow, 48' x 48', one round, upflow, 60' diameter
   g. Total Volume: 331,000 gallons
   h. Surface Area: 7,650 ft^2
   i. Overflow Rate: 130 gpd/ft^2
   j. Return Sludge Capacity: 1 MGD
   k. Return Sludge Rate: usually 0.5 MGD
   l. Sludge wasted either to aerobic digestion tank or to primary

6. Sludge Disposal

   Mixture of primary and waste activated sludge treated with coagulant, filtered, and buried. Filtrate returned through treatment plant

7. Operational History

   No particular problems previous to 1963 when bakery started operation. 1963-1966 almost continuous problems with bulking and deflocculation. Fall 1966 - problems corrected by increasing air supply rate, adding primary solids to mixed liquor, and converting from conventional to contact aeration process.

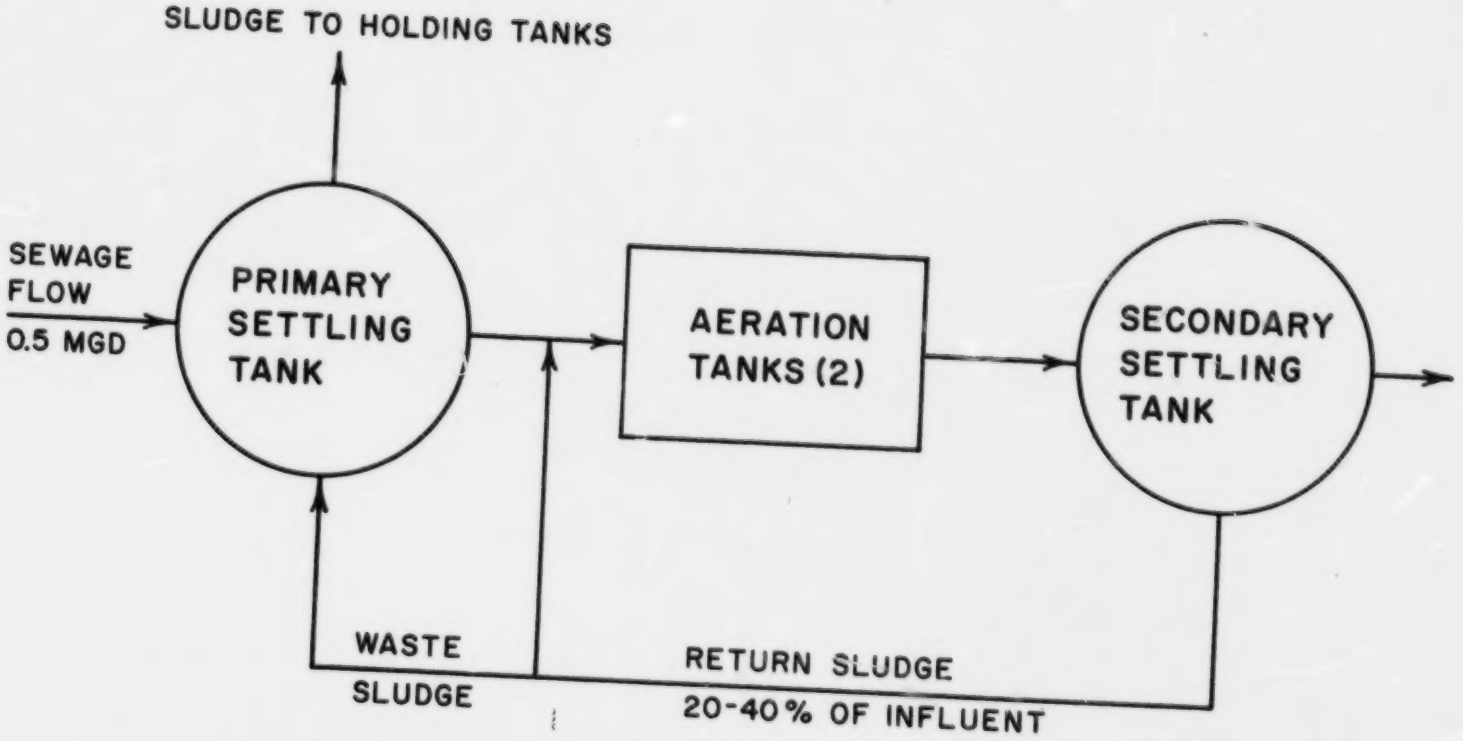

FIG. 3 - SCHEMATIC FLOW DIAGRAM OF SEWAGE TREATMENT PLANT IN FOX RIVER GROVE

1. Identification

   a. Location: Fox River Grove, Illinois
   b. Responsible Agency: Village of Fox River Grove
   c. Information obtained from: Paul Wujcik, Utilities Manager

2. Wastes Treated

   a. Total Flow: 0.5 MGD
   b. Industrial Wastes: Metal Plating Plant - acid and heavy metals
      Aluminum Anodizing Plant - acid and dyes

3. Pretreatment

   Screening and grit removal

4. Primary Treatment

   a. One primary settling tank, circular, upflow, 18' diameter
   b. Total Volume: 5700 gallons
   c. Detention Time: 0.27 hours
   d. Surface Area: 254 square feet
   e. Surface Loading: 2000 gpd/ft^3

5. Activated Sludge Process (Conventional)

   a. Two aeration tanks operated in parallel
   b. Total Volume: 89,500 gallons
   c. Detention Time: 4.3 hours
   d. Mechanical aeration
   e. One secondary settling tank, circular, upflow, 24' diameter
   f. Total Volume: 27,100 gallons
   g. Surface Area: 450 ft^2
   h. Overflow Rate: 1,100 gpd/ft^2
   i. Return Sludge Rate: not known
   j. Sludge wasted to primary as needed

6. Sludge Disposal

   Holding tank for concentration and burial of waste sludge

7. Operational History

   Problems with loss of very fine suspended solids and white precipitate for several years.

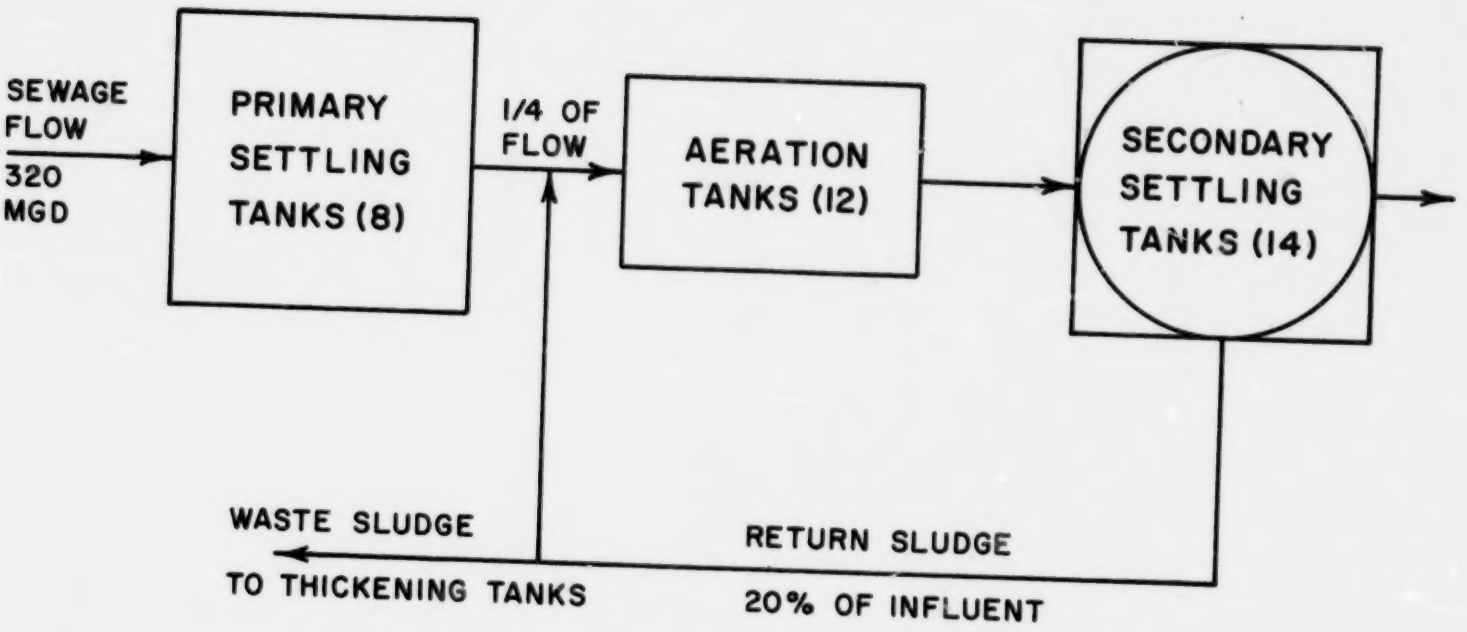

FIG. 4 - SCHEMATIC FLOW DIAGRAM OF ONE BATTERY AT NORTH SIDE TREATMENT WORKS, CHICAGO, ILLINOIS

1. Identification

   a. Location: Chicago, Illinois (North Side Sewage Treatment Works)
   b. Responsible Agency: Metropolitan Sanitary District of Greater Chicago
   c. Information obtained from: T. Ladd, Superintendent

2. Wastes Treated

   a. Total Flow: 300 to 400 MGD
   b. Industrial Wastes: Large variety of types make up only a small fraction of flow

3. Pretreatment

   Screening and grit removal

4. Primary Treatment

   a. Eight primary settling tanks, square, upflow, each 80' x 80' x 13'
   b. Total Volume: 5,000,000 gallons
   c. Detention Time: 0.375 hours at 320 MGD
   b. Surface Area: 51,200 ft^2
   e. Overflow Rate: 7825 gpd/ft^2

5. Activated Sludge Process (Conventional)

   Four batteries which are actually four separate activated sludge processes. The following are a description of one battery assuming a flow of 80 MGD

   a. Twelve aeration tanks, each 34.75' x 450' x 15'
   b. Total Volume: 21,100,000 gallons
   c. Detention Time: 6.35 hours
   d. Diffused Air Capacity: 120 cfm
   e. Air Supply Rate: 1.45 ft^3/gal
   f. Fourteen secondary settling tanks, ten are square, upflow, each 77' x 77' x 16'; four are circular, upflow, 75' diameter by 14.75' deep
   g. Total Volume: 9,150,000 gallons
   h. Surface Area: 77,840 ft^2
   i. Overflow Rate: 1030 gpd/ft^2
   j. Return Sludge Capacity: 30 MGD
   k. Return Sludge Rate: Usually 20 to 30%
   l. Sludge wasted to thickening tanks

6. Sludge Disposal

   Sludge thickened and pumped to West-Southwest Treatment Works

7. Operational History

   Plant usually performs well, but bulking often occurs in late summer or early fall.

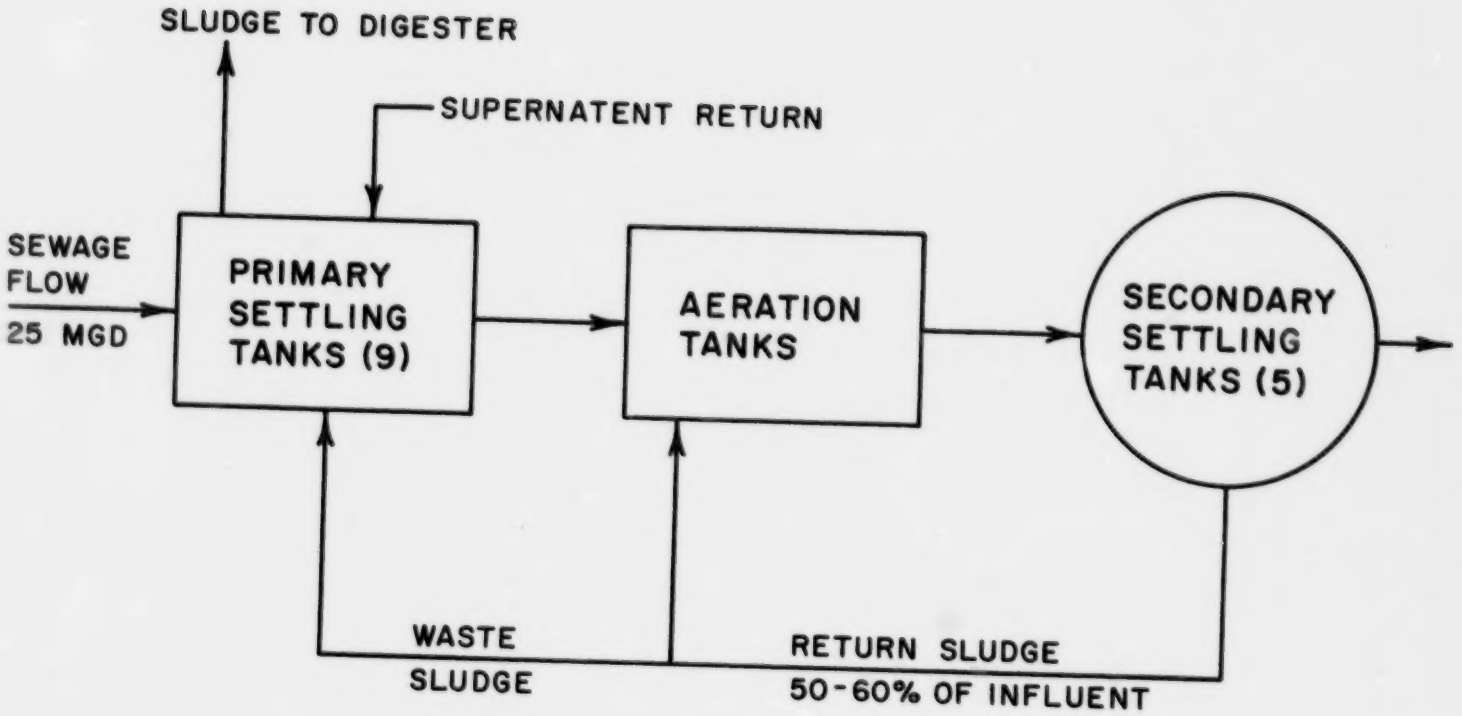

FIG. 5 - SCHEMATIC FLOW DIAGRAM OF FT. WAYNE TREATMENT PLANT

1. Identification

   a. Location: Fort Wayne, Indiana
   b. Responsible Agency: City of Fort Wayne
   c. Information obtained from: Paul L. Brunner, Superintendent

2. Wastes Treated

   a. Total Flow: 24.8 MGD - 1965 average
   b. Variation: 14.7 to 52.4 MGD
   c. Industrial Wastes: Electrical Manufacturing - solvents and cresylic acid; Brewery Wastes

3. Pretreatment

   a. Screening ground and returned to flow
   b. Grit removal

4. Primary Treatment

   a. Nine primary settling tanks, rectangular, horizontal flow
   b. Total Volume: 2,210,000 gallons
   c. Detention Time: 2.1 hours

5. Activated Sludge Process (Conventional)

   Five identical processes usually operated in parallel

   a. Five aeration tanks, each 2,100,000 gallons
   b. Total Volume: 10,500,000 gallons
   c. Detention Time: 10.2 hours
   d. Diffused Air Capacity: 32,000 cfm
   e. Air Supply Rate: 1.17 ft^3/gal
   f. Five secondary settling tanks, circular, upflow, each 110' diameter
   g. Total Volume: 5,000,000 gallons
   h. Surface Area: 520 gpd/ft^2
   i. Return Sludge Capacity: 18 MGD
   j. Return Sludge Rate: usually 50-60%
   k. Sludge wasted to primary as needed

6. Sludge Disposal

   Anaerobic digestion and air drying

7. Operational History

   Chronic bulking condition for past five years

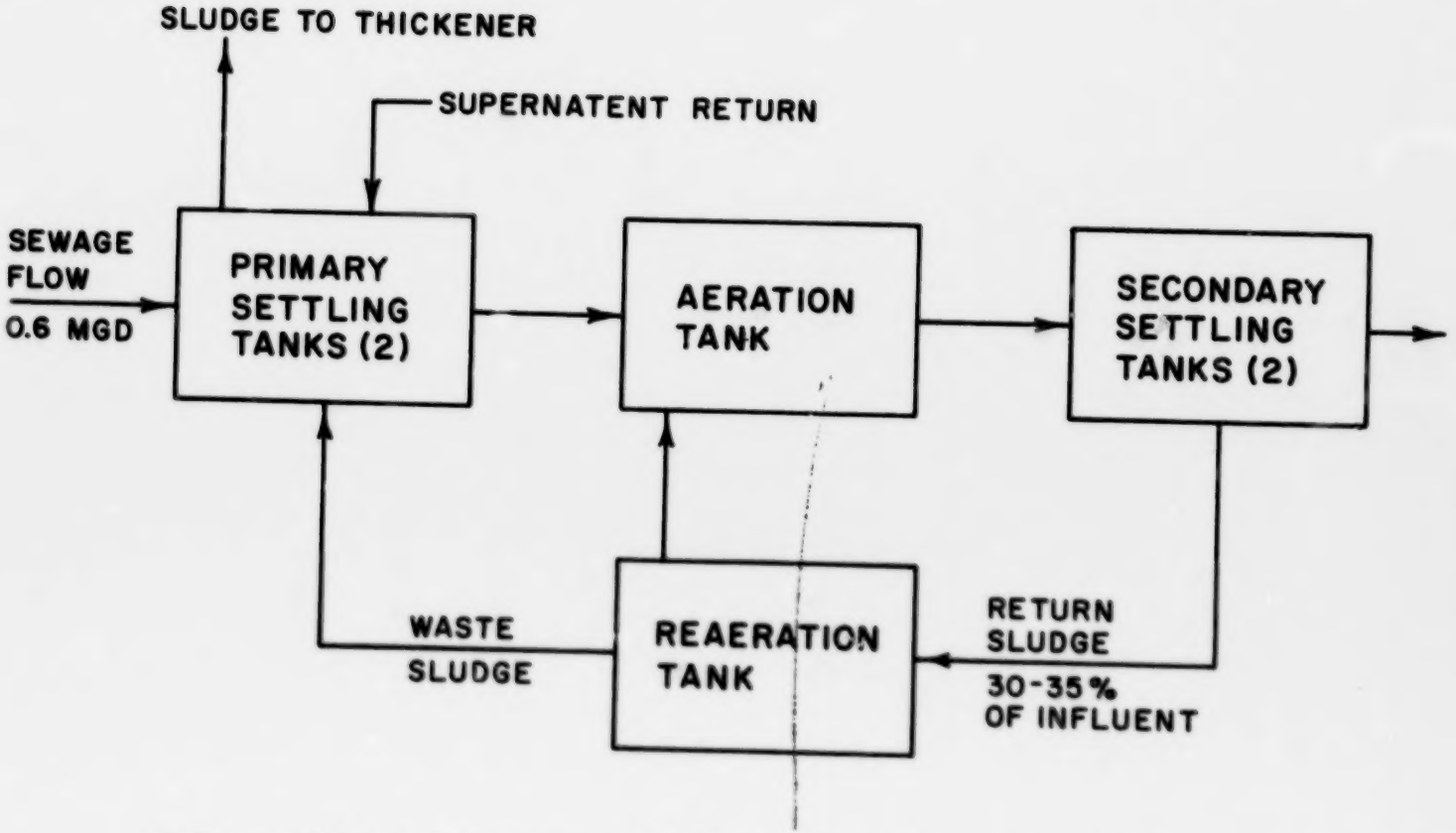

FIG. 6 - SCHEMATIC FLOW DIAGRAM OF TREATMENT WORKS AT McHENRY, ILLINOIS

1. Identification

   a. Location: McHenry, Illinois
   b. Responsible Agency: City of McHenry
   c. Information obtained from: Howard Dowell, Chief Operator

2. Wastes Treated

   a. Total Flow: 0.6 MGD
   b. Industrial Wastes: Feed Mill, Wax Factory, Radio Factory

3. Pr treatment

   Screening and grit removal

4. Primary Treatment

   a. Two primary settling tanks, rectangular, horizontal flow, one is 13' x 40' x 9.83' and the other is 9.5' x 40' x 9.83'
   b. Total Volume: 66,200 gallons
   c. Detention Time: 2.65 hours
   d. Surface Area: 9,000 ft^2
   e. Overflow Rate: 667 gpd/ft^2

5. Activated Sludge Process (Contact Aeration)

   a. One contact tank, 52.5' x 23.5' x 15.67'
      One reaeration tank, 52.5' x 23.5' x 15.67'
   b. Total Volume: 290,000 gallons
   c. Detention Time: 11.6 hours
   d. Diffused Air Capacity: not known
   e. Air Supply Rate: not known
   f. Two secondary settling tanks, rectangular, horizontal flow, each 52.5' x 12' x 10.5'
   g. Total Volume: 99,500 gallons
   h. Surface Area: 1260 ft^2
   i. Overflow Rate: 475 gpd/ft^2
   j. Return Sludge Capacity: 0.45 MGD
   k. Retur. Sludge Rate: usually 30-35%
   l. Sludge wasted to primary as needed; usually 3200 gallons/day

6. Sludge Disposal

   Mixture of primary sludge and waste activated sludge thickened and trucked away for burial. Supernatent from thickener returned to primary.

7. Operational History

   Plant usually performs well except when upset by dumping of waste from wax factory or feed mill

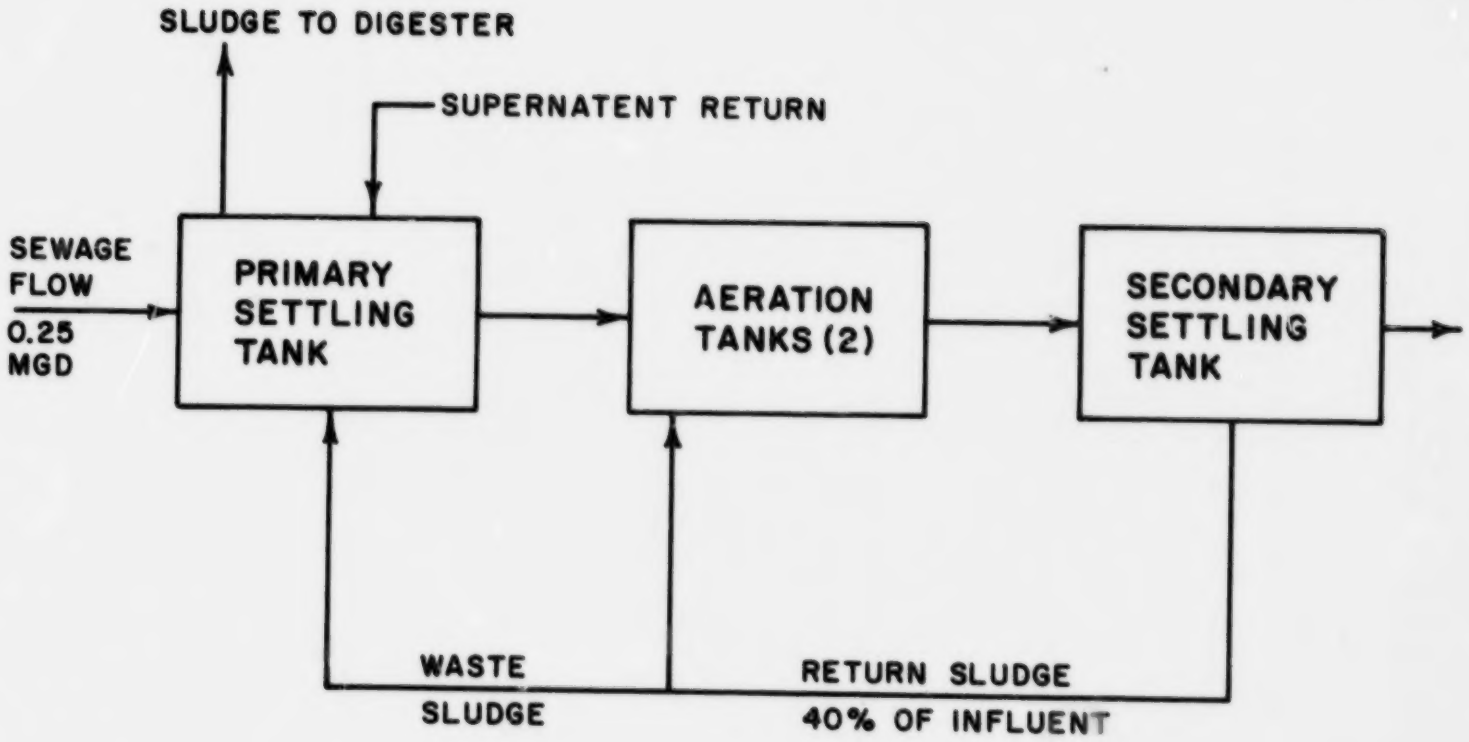

FIG. 7 - SCHEMATIC FLOW DIAGRAM OF TREATMENT WORKS AT MILTON, WISCONSIN

1. Identification

   a. Location: Milton, Wisconsin
   b. Responsible Agency: City of Milton
   c. Information obtained from: Charles Bringham, Director of Public Works

2. Wastes Treated

   a. Total Flow: unmetered; water pumpage for city is 0.23 to 0.25 MGD
   b. Industrial Wastes: Wash water from milk receiving plant, occasionally large amounts of sour milk

3. Pretreatment

   Screening and grit removal

4. Primary Treatment

   a. One primary settling tank, rectangular, horizontal flow, 12' x 31.62' x 9'
   b. Total Volume: 25,500 gallons
   c. Detention Time: 2.45 hours
   d. Surface Area: 380 ft^2
   e. Overflow Rate: 660 gpd/ft^2

5. Activated Sludge Process (Conventional)

   a. Two aeration tanks, each 64,150 gallons
   b. Total Volume: 128,300 gallons
   c. Detention Time: 12.3 hours
   d. Diffused Air Capacity: 600 cfm
   e. Air Supply Rate: 2.3 ft^3/gal
   f. One secondary settling tank, rectangular, horizontal flow, 14' x 40' x 10'
   g. Total Volume: 42,000 gallons
   h. Surface Area: 560 ft^2
   i. Overflow Rate: 460 $gpsl/ft^2$
   j. Return Sludge Capacity: unknown
   k. Return Sludge Rate: Probably 40%
   l. Sludge wasted to primary as needed

6. Sludge Disposal

   Anaerobic digestion and burial

7. Operational History

   Bulking condition (SVI 200) occurs about once a year, usually in the spring. Best operation when sludge volume index is between 100 and 150. Effluent becomes very turbid when sludge volume index is less than 100.

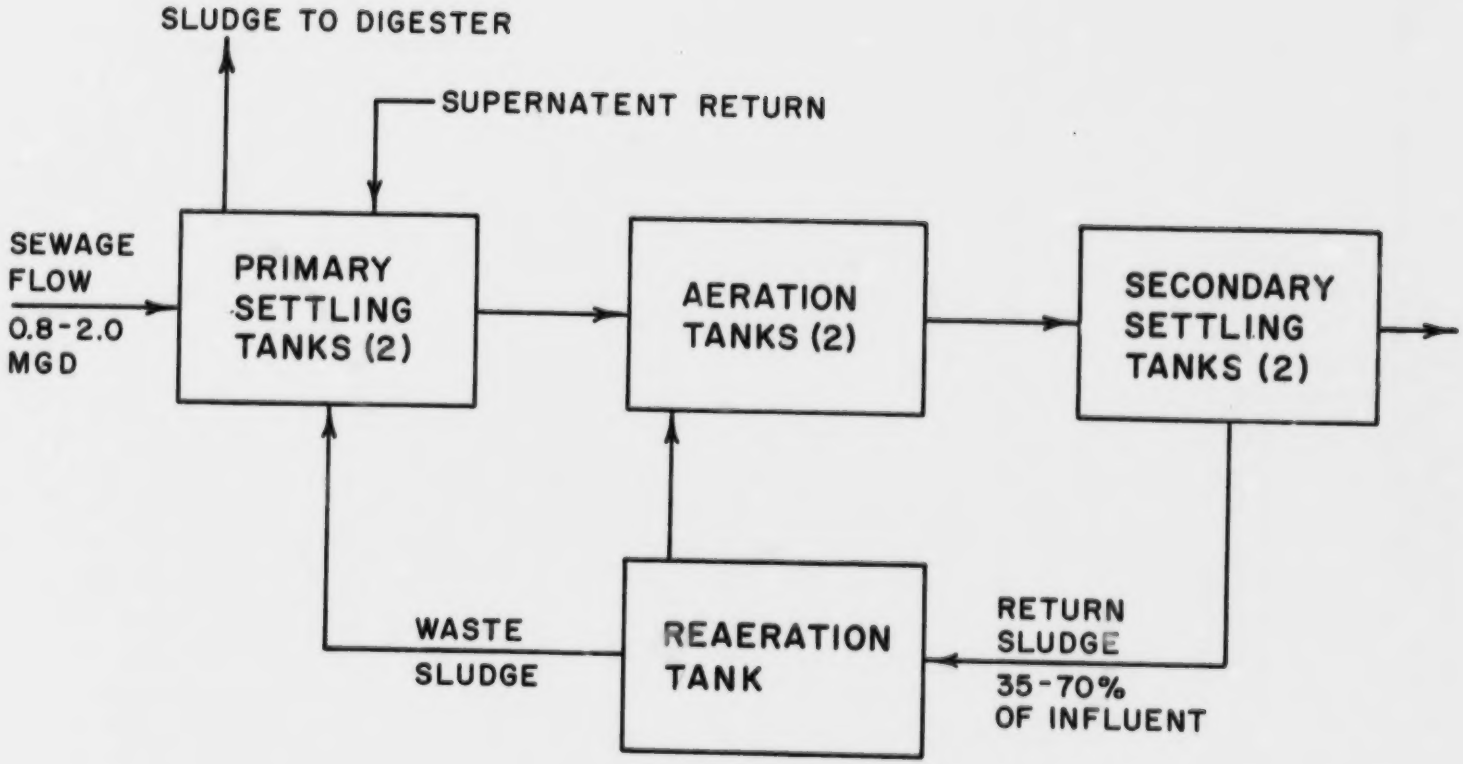

FIG. 8 - SCHEMATIC FLOW DIAGRAM OF TREATMENT WORKS AT BROOKFIELD, WISCONSIN

1. Identification

   a. Location: Brookfield, Wisconsin
   b. Responsible Agency: City of Brookfield
   c. Information obtained from: John Budde, Superintendent

2. Wastes Treated

   a. Total Flow: 1 MGD
   b. Variation: 0.8 MGD - dry weather
      2.5 MGD - wet weather
   c. Industrial Wastes: none

3. Pretreatment

   Screening and grit removal

4. Primary Treatment

   a. Two primary settling tanks, rectangular, horizontal flow, each 5880 ft^3
   b. Total Volume: 89,000 gallons
   c. Detention Time: 2.14 hours
   d. Surface Area:
   e. Overflow Rate:

5. Activated Sludge Process (Conventional process converted to contact aeration in Jan., 1967)

   a. Two aeration tanks, each 173,000 gallons
   b. Total Volume: 346,000 gallons
   c. Detention Time: 8.3 hours
   d. Diffused Air Capacity:
   e. Air Supply Rate: 1.7 ft^3/gal
   f. Two secondary settling tanks, rectangular, horizontal flow, each 64,000 gallons
   g. Total Volume: 128,000 gallons
   h. Surface Area:
   i. Overflow Rate:
   j. Return Sludge Capacity: 0.71 MGD
   k. Return Sludge Rate: usually 71%
   l. Sludge wasted to primary usually at 30,000 gallons per day

6. Sludge Disposal

   Anaerobic digestion and drying beds

7. Operational History

   Best operation at flow near 1 MGD. Chronic bulking when flow drops below 0.9 MGD
   Sludge particles lost from secondary settling tank when flow gets above 1.5 MGD

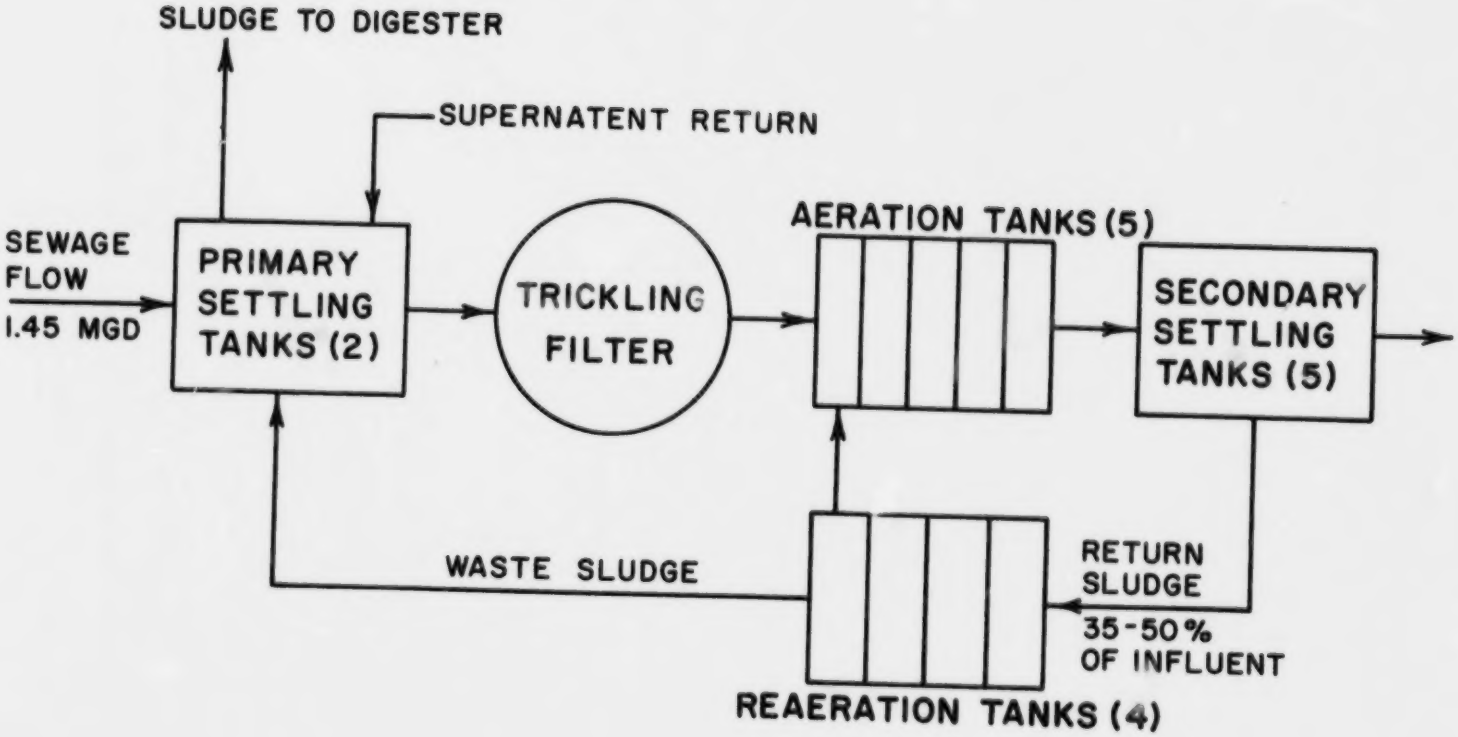

FIG. 9 - SCHEMATIC FLOW DIAGRAM OF TREATMENT WORKS AT WOODSTOCK, ILLINOIS

1. Identification

   a. Location: Woodstock, Illinois
   b. Responsible Agency: City of Woodstock
   c. Information obtained from: James Bates, Superintendent

2. Wastes Treated

   a. Total Flow: 1.45 MGD
   b. Industrial Wastes: 0.25 MGD effluent from activated sludge treating milk processing and doing products wastes Plating Wastes, Rug Cleaning, Tool & Dye Manufacture (very small amounts)

3. Pretreatment

   a. Screening and grit removal
   b. Preaeration

4. Primary Treatment

   a. Two primary settling tanks, rectangular, horizontal flow, each 14' x 60' x 7.5'
   b. Total Volume: 94,000 gallons
   c. Detention Time: 1.57 hours
   d. Surface Area: 1680 ft^2
   e. Overflow Rate: 865 gpd/ft^2

5. Intermediate Treatment

   a. One trickling filter, 70' diameter, 6' deep
   b. Area: 3850 ft^2
   c. Loading: 377 gpd/ft^2

6. Activated Sludge Process (Tanks-in-series with reaeration of return sludge)

   a. Nine aeration tanks, seven are 36,000 ft^3 and two are 33,600 ft^3. 0.1 MGD from trickling filter and all of return sludge to no. 1 tank; 1.35 MGD from trickling filter to no. 5 tank
   b. Total Volume: 2,394,000 gallons
   c. Detention Time: 39.5 hours
   d. Diffused Air Capacity:
   e. Air Supply Rate: 1.67 ft^3/gal
   f. Five secondary settling tanks, rectangular, horizontal flow, two are 10' x 44' x 9.3', two are 14' x 44' x 9.3', and one is 12' x 44' x 8.75'
   g. Total Volume: 178,500 gallons
   h. Surface Area: 2,640 ft^2
   i. Overflow Rate: 500 gpd/ft^2
   j. Return Sludge Capacity: 1.4 MGD
   k. Return Sludge Rate: usually 35-50%
   l. Sludge wasted to primary as needed

7. Sludge Disposal

   Anaerobic digestion and drying beds

8. Operational History

   Plant has operated very well except for upsets due to wastes from dairy products plants. No problems since dairy plant installed its own waste treatment process.

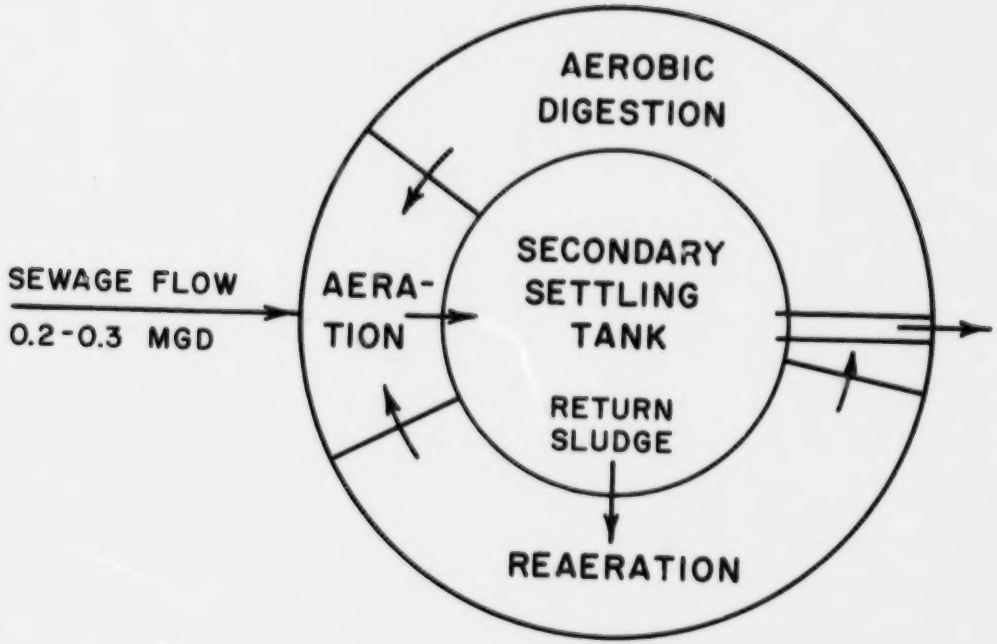

FIG. 10-SCHEMATIC FLOW DIAGRAM OF TREATMENT WORKS AT GAGES LAKE, ILLINOIS

1. Identification

   a. Location: Gages Lake, Illinois (Edic Road Plant)
   b. Responsible Agency: Gages Lake Sanitary District
   c. Information obtained from: Ronald Starostovic, Chief Operator

2. Wastes Treated

   Domestic Sewage only 0.2 to 0.3 MGD
   13,500 connections, flow not metered
   no industrial wastes

3. Pretreatment

   Screening and grit removal

4. Primary Treatment

   none

5. Activated Sludge Process (Contact Aeration with Aerobic Digestion and no provision for sludge disposal)

   a. Three aeration tanks, contact tank is 48,200 gallons, reaeration tank is 87,300 gallons, and aerobic digestion tank is 125,000 gallons)
   b. Total Volume: 260,500 gallons
   c. Detention Time: 24 hours
   d. Diffused Air Capacity: 1740 cfm
   e. Air Supply Rate: 0.55 ft^3/gallon
   f. One secondary settling tank, circular, upflow, 25.67' diameter
   g. Total Volume: 59,500 gallons
   h. Surface Area: 520 ft^2
   i. Overflow Rate: 500 gpd/ft^2
   j. Return Sludge Capacity: 72,000 gpd-air lift
   k. Return Sludge Rate: usually 25%
   l. Sludge wasted in effluent when secondary settling tank can not hold it.

6. Sludge Disposal

   Stream bed; anaerobic digestion and washing away of accumulated sludge during high flows

7. Operational History

   Plant his lost rising and floating sludge periodically during its five years of operation

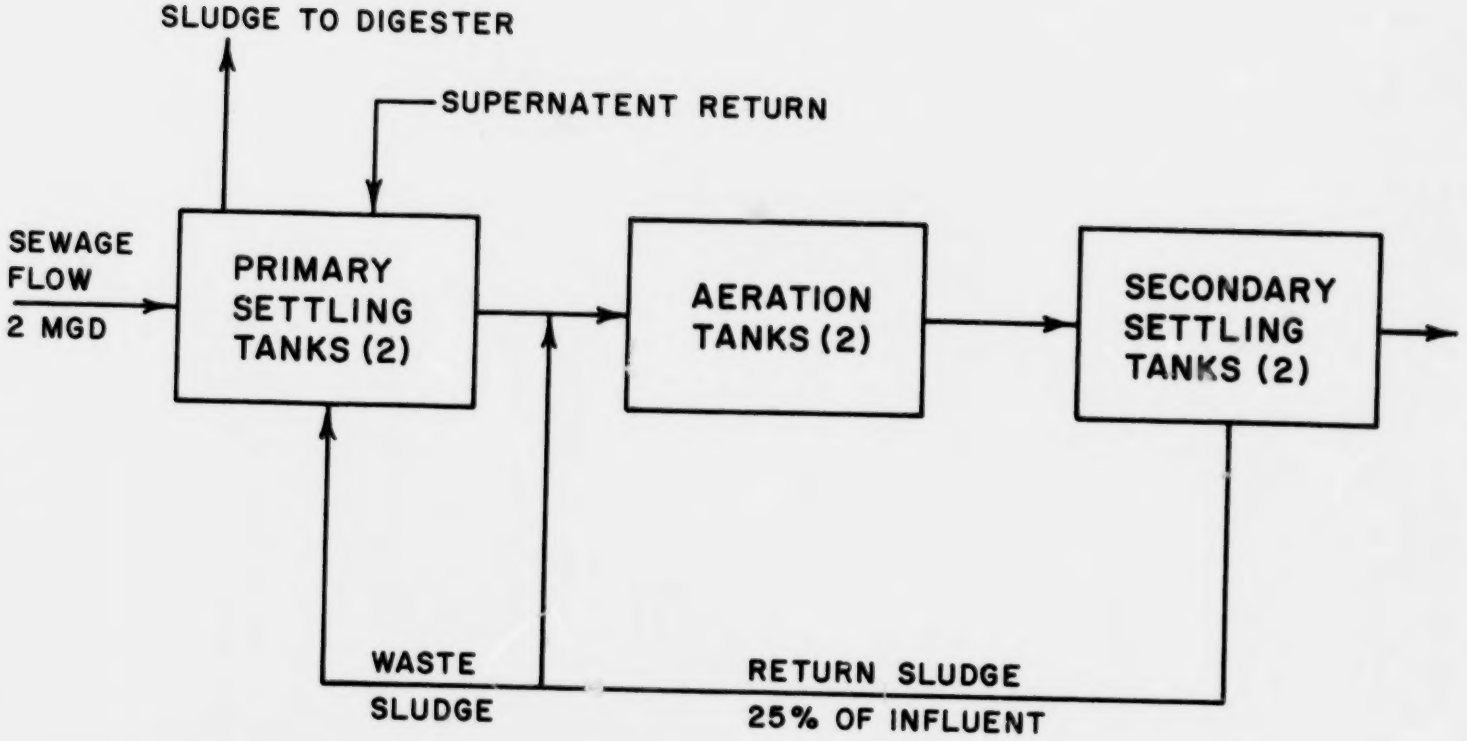

FIG. 11 - SCHEMATIC FLOW DIAGRAM OF LIBERTYVILLE TREATMENT PLANT

1. Identification

   a. Location: Libertyville, Illinois
   b. Responsible Agency: Village of Libertyville
   c. Information obtained from: Gary Smith, Chief Operator

2. Wastes Treated

   a. Total Flow: 2 MGD
   b. Industrial Wastes: Metal plating, machine manufacture, Macaroni factory and research laboratory (very small amounts)

3. Pretreatment

   Screening and grit removal

4. Primary Treatment

   a. Two primary settling tanks, rectangular, horizontal flow, each 20' x 36' x 8'
   b. Total Volume: 86,000 gallons
   c. Detention Time: 1.03 hours
   d. Surface Area: 1440 ft^2
   e. Overflow Rate: 1390 gpd/ft^2

5. Activated Sludge Process (Conventional)

   a. Two aeration tanks, each 20' x 123' x 13'
   b. Total Volume: 480,000 gallons
   c. Detention Time: 5.76 hours
   d. Diffused Air Capacity: 2880 cfm
   e. Air Supply Rate: 1.37 ft^3/gal
   f. Two secondary settling tanks, rectangular, horizontal flow, each 20' x 63' x 8'
   g. Total Volume: 150,000 gallons
   h. Surface Area: 2520 ft^2
   i. Overflow Rate: 790 gpd/ft^2
   j. Return Sludge Capacity: 2.5 MGD
   k. Return Sludge Rate: usually 25%
   l. Sludge wasted to primary settling tank as needed

6. Sludge Disposal

   Anaerobic digestion and drying beds

7. Operational History

   None. Plant put into operation in December, 1966.

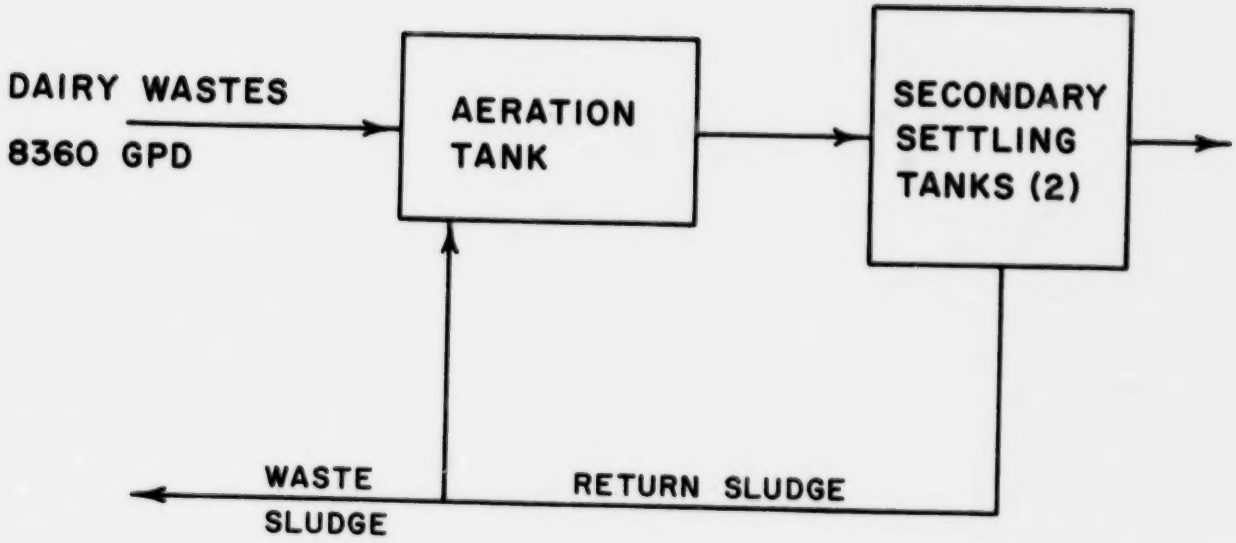

FIG. 12 - SCHEMATIC FLOW DIAGRAM OF ACTIVATED SLUDGE PROCESS AT SPINNEY RUN FARMS DAIRY

1. Identification

   a. Plant Location: Route 63, north of Libertyville, Illinois
   b. Responsibie Agency: Spinney Run Farms Dairy
   c. Information obtained from: John H. Bleck, Consulting Engineer

2. Wastes Treated

   a. Total Flow: 8650 gpd
   b. Entirely wastes from milk processing plant

3. Pretreatment

   Screening

4. Primary Treatment

   None. Two holding tanks with total volume of 8360 gallons used for equalizing flow

5. Activated Sludge Process

   a. One aeration tank
   b. Total Volume: 15,000 gallons
   c. Detention Time: 43 hours
   d. Air Supply: 80 cfm
   e. Air Supply Rate: 13.6 ft^3
   f. Two secondary settling tanks, square, upflow
   g. Total Volume: 2500 gallons
   h. Surface Area: 15 ft^2
   i. Overflow Rate: 565 gpd/ft^2
   j. Return Sludge: Air lift pumps, unmetered
   k. Sludge wasted to holding tank

6. Sludge Disposal

   Spreading on pasture land

7. Operational History

   Plant has had long history of problems with sludge separation probably due to poor control of return sludge rate.

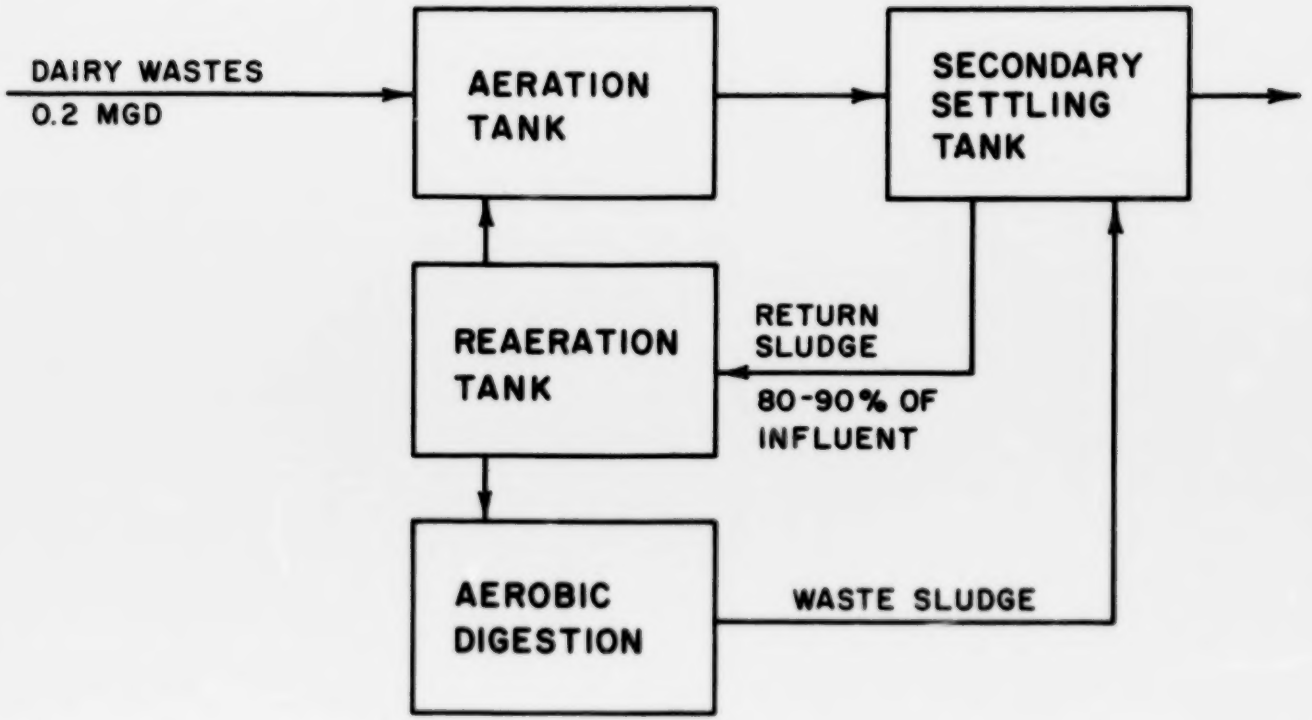

FIG. 13 - SCHEMATIC FLOW DIAGRAM OF ACTIVATED SLUDGE PROCESS AT BORDEN'S DAIRY, WOODSTOCK, ILLINOIS

1. Identification

   a. Location: Woodstock, Illinois
   b. Responsible Agency: Borden's Dairy Co.
   c. Information obtained from: Ross W. Koon

2. Wastes Treated

   a. Normal Flow: 0.2 MGD entirely wastes from dairy products manufacture
   b. Variation: 0.165 to 0.219
   c. Products Produced: milk, buttermilk, chocolate drink, fruit juices, cottage cheese

3. Pretreatment

   Screening and grit removal

4. Primary Treatment

   None

5. Activated Sludge Process (Contact Aeration with Aerobic Digestion and no provision for sludge disposal).

   a. Four aeration tanks, each 88,000 gallons
      no. 1 used for contact tank
      no. 2 used for reaeration tank
      no. 3 used for aerobic digestion
      no. 4 used for preaeration on neutralization of washings from cottage cheese
   b. Total Volume: 264,000 gallons
   c. Detention Time: 31.4 hours
   d. Air Supply: Combination of diffused air and mechanical aeration; compressed air supplied at 2800 cfm
   e. Air Supply Rate: 20 ft^3/gal + mechanical aeration
   f. One secondary setting tank, rectangular, horizontal flow
   g. Total Volume: 45,000 gallons
   h. Surface Area: 500 ft^3
   i. Overflow Rate: 400 gpd/ft^2
   j. Return Sludge Capacity: 0.374 MGD
   k. Return Sludge Rate: 0.187 MGD
   l. Sludge pumped to aerobic digester at 0.0935 MGD

6. Sludge Disposal

   Excess sludge lost in effluent to city sewers

7. Operational History

   Process has never operated properly. Separated disposal of whey from cottage cheese manufacture improved operation somewhat.

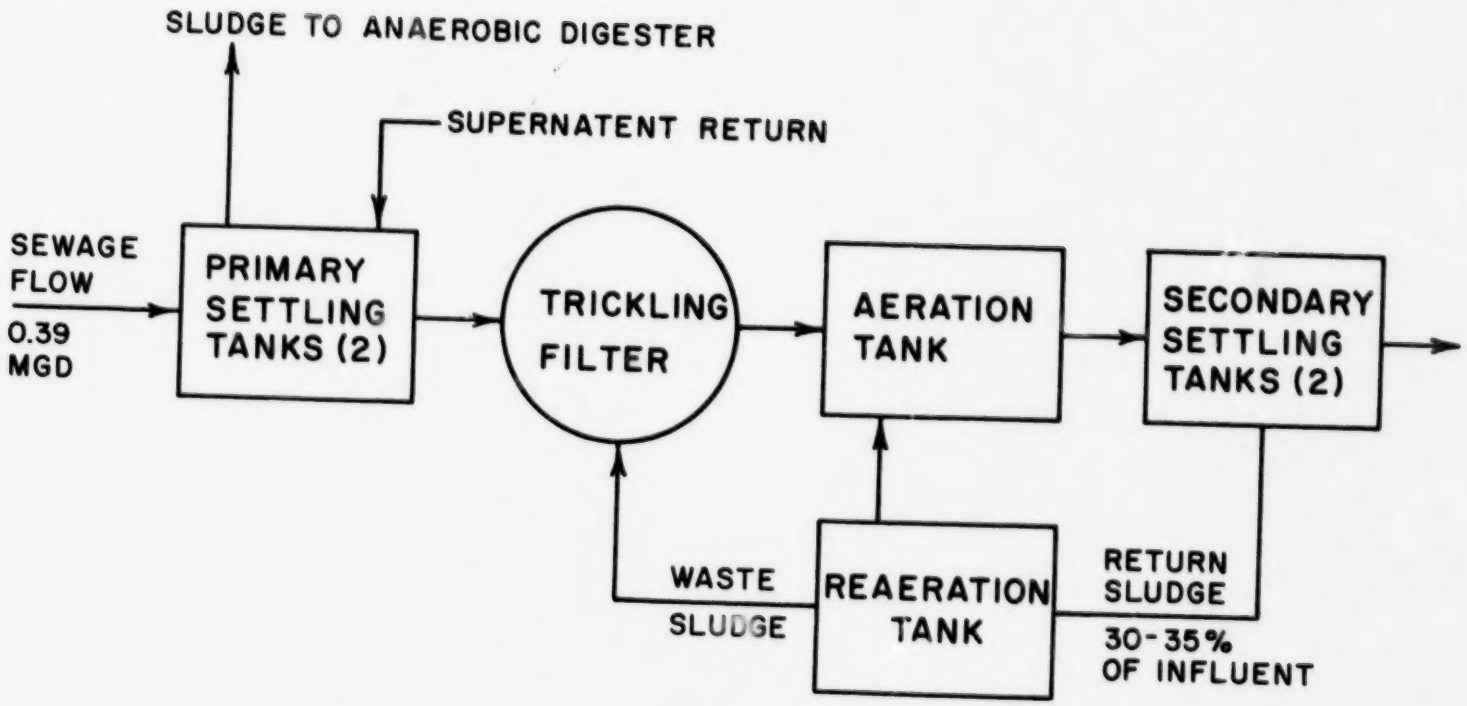

FIG. 14-SCHEMATIC FLOW DIAGRAM OF SEWAGE TREATMENT PLANT AT ANTIOCH, ILLINOIS

1. Identification

   a. Location: Antioch, Illinois
   b. Responsible Agency: Village of Antioch
   c. Information obtained from: Charles P. Maplethorpe, Chief Operator

2. Wastes Treated

   a. Total Flow: 0.39 MGD
   b. Variation: 0.30 to 0.75 MGD
   c. Industrial Wastes: Dairy Wastes 18,000 gpd, ink manufacture

3. Pretreatment

   Screening and grit removal

4. Primary Treatment

   a. Two primary settling tanks, rectangular, horizontal flow, each 10' x 36' x 8.5'
   b. Total Volume: 45,800 gallons
   c. Detention Time: 2.82 hours
   d. Surface Area: 720 ft^2
   e. Overflow Rate: 542 gpd/ft^2

5. Intermediate Treatment

   a. One trickling filter, 75' diameter, 6' deep
   b. Area: 4430 ft^2
   c. Loading: 88 gpd/ft^2

6. Activated Sludge Process (Contact Aeration)

   a. One Contact tank, 28' x 28' x 14'
   b. One reaeration tank, 28' x 28' x 14'
   c. Total Volume: 82,200 gallons
   d. Detention Time: 5.06 hours
   e. Mechanical Aeration:
   f. Two secondary settling tanks, rectangular, horizontal flow, each 10' x 31' x 8'
   g. Total Volume: 34,100 gallons
   h. Surface Area: 620 ft^2
   i. Overflow Rate: 630 gpd/ft^2
   j. Return Sludge Capacity: 0.25 MGD
   k. Return Sludge Rate: usually 0.15 MGD
   l. Sludge wasted as needed to maintain a 30 minute settled volume of 20 to 30% in contact tank

7. Sludge Disposal

   Anaerobic digestion and drying beds

8. Operational History

   No history of operational difficulties

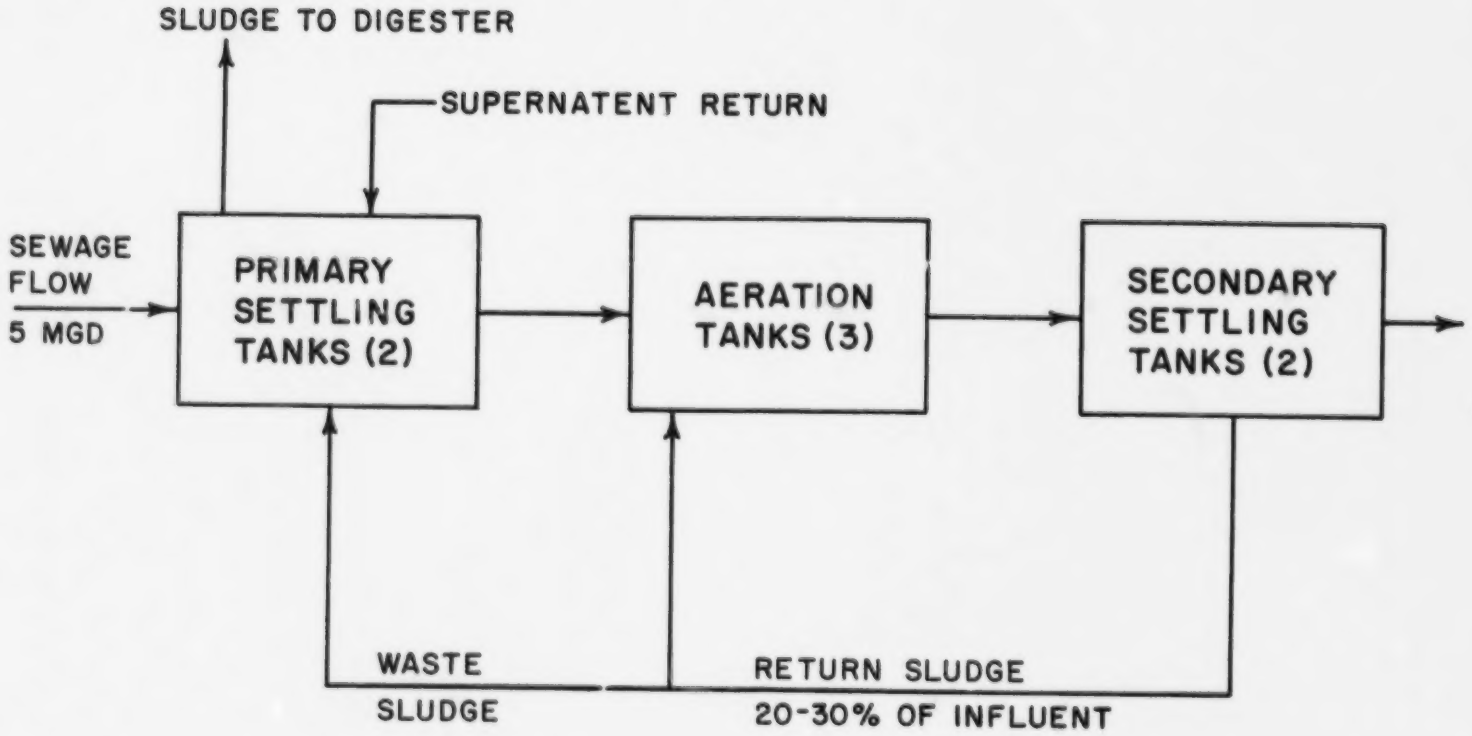

FIG. 15-SCHEMATIC FLOW DIAGRAM OF CLAVEY ROAD TREATMENT WORKS OF THE NORTH SHORE SANITARY DISTRICT

1. Identification

   a. Location: Highland Park, Illinois (Clavey Road Plant)
   b. Responsible Agency: North Shore Sanitary District
   c. Information obtained from: Carl Stauche, Chief Operator

2. Wastes Treated

   a. Total Flow: 5 MGD (maximum flow of 22 MGD during heavy rains)
   b. Industrial Wastes: Dairy wastes, cosmetics manufacture (small amounts)

3. Pretreatment

   Screening and grit removal

4. Primary Treatment

   a. Two primary settling tanks, rectangular, horizontal flow, each 135,000 gallons
   b. Total Volume: 270,000 gallons
   c. Detention Time: 1.3 hours
   d. Surface Area: 2400 ft^2
   e. Overflow Rate: 2080 gpd/ft^2

5. Activated Sludge Process (Conventional)

   a. Three aeration tanks, each 370,000 gallons
   b. Total Volume: 1,110,000 gallons
   c. Detention Time: 4.9 hours
   d. Diffused Air Capacity:
   e. Air Supply Rate:
   f. Two secondary settling tanks, rectangular, horizontal flow, each 259,200 gallons, 15' day
   g. Total Volume: 518,400 gallons
   h. Surface Area: 4,600 ft^2
   i. Overflow Rate: 1090 gpd/ft^2
   j. Return Sludge Capacity: 1.6 MGD
   k. Return Sludge Rate: usually 20%
   l. Sludge wasted to primary as needed

6. Sludge Disposal

   Anaerobic digestion and drying beds

7. Operational History

   Plant usually operates well. Occasional problems with billowing sludge and septic sludge.

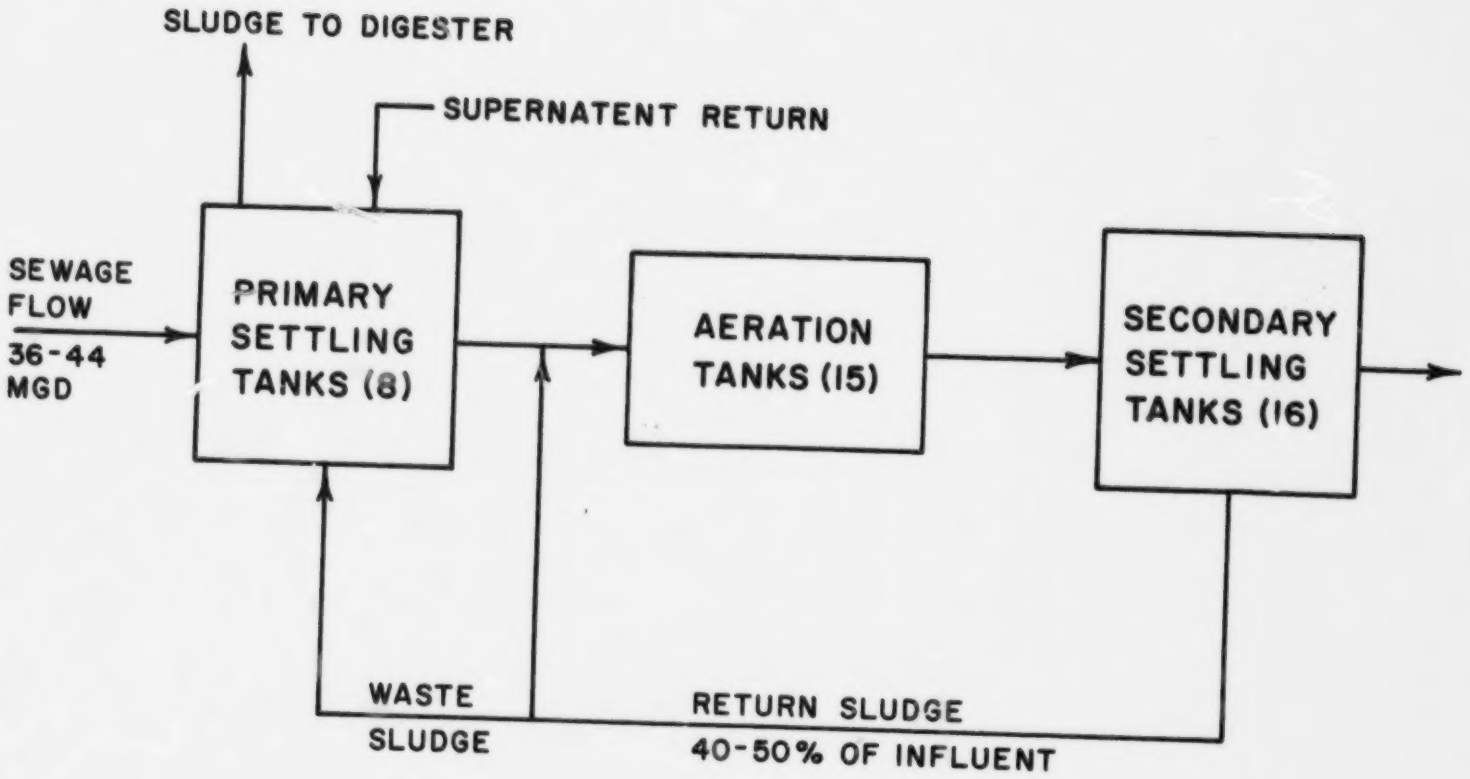

FIG. 16 - SCHEMATIC FLOW DIAGRAM OF GARY TREATMENT PLANT

1. Identification

   a. Location: Gary, Indiana
   b. Responsible Agency: Gary Sanitary District
   c. Information obtained from: F. Leonard Coventry, Superintendent
      Nicholas Cost, Assistant Superintendent

2. Wastes Treated

   a. Total Flow: 42.1 MGD - 1966 average
   b. Industrial Wastes: Ammonia still wastes from coke plant approximately 200,000 gals/day.
      Chicken processing plant

3. Pretreatment

   a. Screenings (1" bar screens) removed for burial
   b. Grit removal

4. Primary Treatment

   a. Eight primary settling tanks, square, upflow, each 75' x 75' x 11'
   b. Total Volume: 3,710,000 gallons
   c. Detention Time: 2.11 hours
   d. Surface Area: 45,000 square feet
   e. Overflow Rate: 938 gpd/ft^2

5. Activated Sludge (Conventional)

   a. Fifteen aeration tanks operated in parallel, each 30' x 300' x 15'
   b. Total Volume: 15,200,000 gallons
   c. Detention Time: 8.66 hours
   d. Diffused Air Capacity: 61,000 cfm
   e. Air Supply Rate: 0.5 ft^3/gal
   f. 16 secondary settling tanks, square, upflow, each 75' x 75' x 11'
   g. Total Volume: 7,420,000 gallons
   h. Surface Area: 90,000 square feet
   i. Overflow Rate: 469 gpd/ft^2
   j. Return Sludge Capacity: 56.5 MGD
   k. Return Sludge Rate: usually 40 to 50%
   l. Sludge wasted to primary settling tanks as needed

6. Sludge Disposal

   Anaerobic digestion and burial of digested sludge

7. Operational History

   Plant in operation for twenty-seven years
   No history of operational difficulties

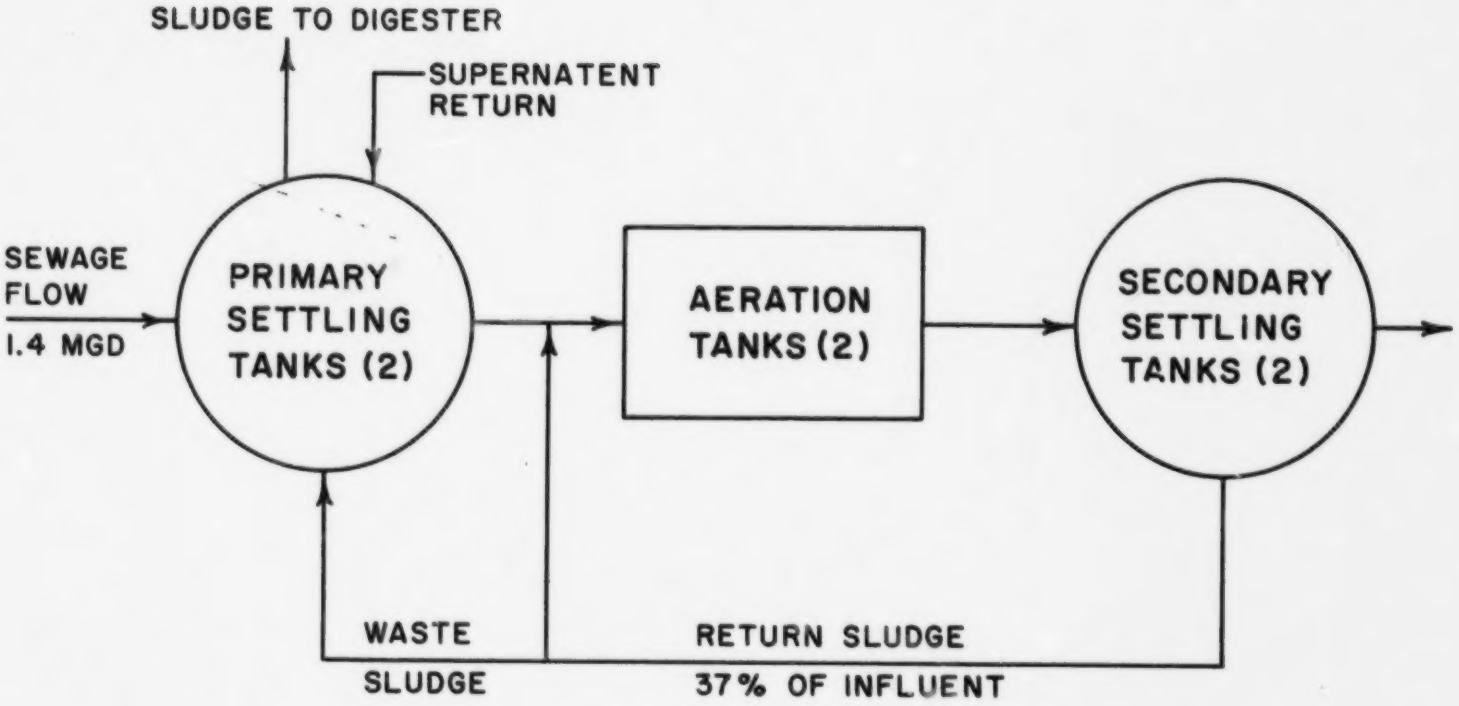

FIG. 17 - SCHEMATIC FLOW DIAGRAM OF HANOVER PARK TREATMENT WORKS

1. Identification

   a. Location: Hanover Park, Illinois
   b. Responsible Agency: Metropolitan Sanitary District of Greater Chicago
   c. Information obtained from: T. McAloon

2. Wastes Treated

   a. Total Flow: 1.4 MGD (dry weather flow)
   b. Variation: to 4.0 MGD
   c. Industrial Wastes: none

3. Pretreatment

   Grinding of large materials

4. Primary Treatment

   a. Two primary settling tanks, circular, upflow; each 45' diameter and 13' deep
   b. Total Volume: 309,000 gallons
   c. Detention Time: 5.3 hours to 1.85 hours
   d. Surface Area: 3180 ft^2
   e. Overflow Rate: 440 gpd/ft^2 to 1260 gpd/ft^2

5. Activated Sludge Process (Conventional)

   a. Two aeration tanks operated in parallel, each 269,000 gallons
   b. Total Volume: 538,000 gallons
   c. Detention Time: 9.6 hours to 3.37 hours
   d. Diffused Air Capacity: 800 cfm
   e. Air Supply Rate: 0.72 ft^3/gal
   f. Two secondary settling tanks, circular, upflow, each 40' diameter and 12' deep (avg).
   g. Total Volume: 227,000 gallons
   h. Surface Area: 2520 ft^2
   i. Overflow Rate: 555 gpd/ft^2 to 1590 gpd/ft^2
   j. Return Sludge Capacity: 0.52 MGD (by air lift)
   k. Return Sludge Rate: 0.52 MGD
   l. Waste Sludge Capacity: 26,000 gpd
   m. Sludge wasted to primary

6. Sludge Disposal

   Anaerobic digestion and land disposal of digested sludge.

7. Operational History

   Sludge volume index usually above 100 ml/gm during dry weather

METHODOLOGY

The overall research plan for this project is to compare samples from different activated sludge processes on the basis of filamentous organisms present in the sludge, influent waste, and effluent. At the same time the physical properties of the sludge, the performance of the secondary settling tanks, the design of the activated sludge process, and values of some of the environmental factors in the aeration tank, and the nature of the wastes being treated are determined. Correlations are sought between some of the values measured in order to provide evidence relating to the validity of the hypotheses.

Since the samples are collected from full scale activated sludge processes, there is no attempt to control any of the variables except by selection of plants to be sampled. This research is descriptive rather than experimental. The objective is to discover phenomena which are actually occuring in operational activated sludge processes.

Samples Collected

In a project of this type, the problem of obtaining representative samples always arises. Individual grab samples have a low probability of giving a true representation of actual conditions. On the other hand, collection of composite samples allows a great deal of time for the material being collected to change its properties before analysis. Also, there is a definite economic limit to the number of samples which can be handled and the analyses which can be made.

The resolution determined in this case is to collect grab samples and transport them to the laboratory for analysis as quickly as possible. Information obtained from the plant operating personnel or laboratory personnel is relied upon to indicate the instances when the grab samples are not representative of the actual conditions in the process. Although the numbers of samples collected on each trip and the analysis performed on each sample are limited, the overall mass of data from sixty sampling trips should allow recognition of exceptional conditions.

Since the primary objective of the project is to provide information about the filamentous organisms in the sludge itself, three or four samples of the sludge are obtained on each sampling trip. Sample 1 is mixed liquor collected at the influent end of the aeration tank, and sample 2 is mixed liquor collected at the effluent end of the aeration tank. Sample 3 is a return sludge sample and is collected wherever possible. Sample 4 was originally intended to be a sample of the waste activated sludge. However, in the plants included in this project, the sludge is always wasted directly from the return sludge line and is wasted only intermittantly. Thus, sample 4 is used for samples of the sludge other than mixed liquor or return sludge when these are available. When the process being sampled includes reaeration, sample 3 is from the influent end of the reaeration tank, and sample 4 from the effluent end of the reaeration tank.

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Sample 5 is of the effluent from the activated sludge process and is always collected ahead of any post treatment unit. This sample is used for determination of the performance of the activated sludge process and the nature of the organisms in the effluent. Many of the plants in this sampling program have post treatment units (chlorination, oxidation ponds, or both) so the analyses of sample five cannot be used to evaluate overall plant performance.

Sample 6 is the influent waste entering the activated sludge process. In most instances, this is settled sewage. Sample 7 is the raw waste before primary treatment. However, three of the plants sampled have no primary treatment and for these plants, there is no sample 7, and sample 6 is the raw waste.

Handling of Samples

All of the samples are collected in presterilized one gallon bottles by immersion of the bottles. The sample bottles are packed in ice for transportation back to the laboratory. The longest time between sample collection and start of the analytical procedures is four hours, and most of the plants being sampled are close enough to the laboratory that the transportation time is less than two hours.

The aliquots use for microbial analysis are removed from the sample bottles first and transferred to sterilized covered beakers. The aliquots for microscopic examination are removed next and then the aliquots for the biochemical oxygen demand (BOD) determinations. The remainder of the sample is divided into two portions, half is used for the physical analyses and the other half for the chemical analyses.

Analyses at Plant

At the time of sampling the temperature, pH, and dissolved oxygen concentration (D.O.) are determined at each of the sampling points. When sample 1 is collected, another sample of the mixed liquor is immediately placed in a one liter cylinder. The sludge in this cylinder is allowed to settle for thirty minutes while the other samples are being collected. The thirty minute settled volume is determined at the plant so that any change in settled volume during the period that the mixed liquor samples are not being aerated will be noticed.

Physical Analyses

The physical analyses of the samples are concerned with the amounts of material suspended and dissolved in the liquid and with the settling and compaction characteristics of the sludge samples. All analyses are made according to procedures described in Standard Methods (4).

The residue on evaporation is determined in triplicate on samples no. 5, 6, and 7 and divided into volatile and fixed portions by ignition.

Total volatile and fixed suspended matter is determined in triplicate on all seven samples and on the supernatents from samples 1 and 2 after the sludge in these samples has been allowed to settle for thirty minutes.

The settlability of the sludges in samples 1, 2, 3 and 4 is determined by allowing the samples to settle quiescently in 1000 ml. graduated cylinders. The sludge volumes are read at 2, 5, 10, 15, 20, 30, 45, 60 and 90 minutes. The sludge volume indices for these four samples is calculated from the total suspended matter and the thirty minute settled volume.

Chemical Analyses

The chemical analyses are made to give a method of evaluating the performance of the activated sludge process and of describing to some extent the environments in the process. The analyses of samples 5, 6, and 7, which are made in the laboratory, are pH, alkalinity, BOD, COD, organic nitrogen and ammonia nitrogen. Sulfide determinations are made on those samples in which the initial dissolved oxygen concentration is very low

The COD of filtered supernatent from settling of samples 1 and 2 is run routinely to give a measure of the amount of dissolved organic matter available in the aeration tank. When rising sludge is encountered, nitrate and nitrate nitrogen in the filtered supernatent is also determined.

Microscopic Examination

All samples collected are examined microscopically to detect any unusual microorganisms present. Notes are made on the numbers and types of protozoa present, presence or absence of fungus mycelia, and appearance of bacterial filaments and clumps. In addition to this cursory examination, the sludge particles in sample 2 are sized and counted and the numbers of filaments in this sample are counted.

Enumeration of sludge particles and filaments is accomplished with a Neubauer hemocytometer. This is a standard laboratory device used in calculating the number of blood cells in one milliliter of whole blood. Samples of mixed liquor are diluted anywhere from one in one to one in eight. A satisfactory dilution is one that provides sufficient dispersion of sample to distinguish individual particles microscopically. A drop of the diluted sludge is then placed on each grid in the hemocytometer and covered with the glass coverslip. The actual loading procedure requires some practice as proper dispersion of sludge particles is frequently difficult to obtain.

The sludge particles and filaments are counted by using a phase contrast microscope at 200X magnification. Particles are noted on a tally sheet along with the number of attached filaments per particle. Particle sizes were also estimated by making comparisons with the smallest divisions in the chamber grid.

The smallest size used in grading particles is a square one-sixteenth of one millimeter on each side or 3906.25 square microns. All particles are then graded according to whole number multiples of the smallest size unit. A range of one through eight is most used.

Calculation of particles and filaments per milliliter of activated sludge can be determined from this formula.

$$\frac{\text{depth correction for a 1/10 mm. deep chamber (10)}}{\text{no. of square millimeters counted per chamber (4)}} \times \text{dilution (x)} \times \text{no. of particles or filaments counted}$$

= no. of filaments or particles per millimeter cubed.
no. of filaments or particles per millimeter cubed x 1,000
= no. of filament or particles per milliliter.

The tally sheets also contain a survey section where noted filament lengths are noted. Protozoans and fungal filaments are recorded as rare, few or many. Observations and comparisons of samples other than mixed liquor (i.e. raw sewage, primary and secondary effluent, etc.) are noted on a separate page.

Bacteriological and Mycological Examination

The objective of the bacteriological examination of the various samples collected on each trip is to grow in culture, recognize, and enumerate any significant filamentous organisms present. Since this includes filamentous bacteria, yeasts, and molds, several different types of media, plating procedures, and incubation periods are required.

Dilutions of the samples are necessary to insure a number of colonies per petri dish which are manageable yet still statistically significant. Three successive ten-fold dilutions of the sample for each different medium was found to be sufficient to bring the counts into the proper range. The dilutions made are dependent on the solids concentration of the sample and the numbers of the organisms in question which are expected to be present.

Prior to sampling, all supplies are sterilized and all media for plating procedures are prepared and sterilized. Pre-packaged, plastic, disposable, sterile petri dishes are used exclusively. Water used for diluting samples is distilled, buffered, bottled in 90 ml. portions in milk dilution bottles, and autoclaved.

The following media are prepared:

GPY agar: 0.5 gm of dextrose, 0.1 gm yeast extract, 0.1 gm neopeptone, 15.0 gm agar, 1000 ml. distilled water.

TGB agar: Tryptone Glucose Extract Agar as recommended by Standard Methods (4) for total plate count. (Prior to 12-15-66, Nutrient Agar was used).

ND agar: Neopeptone--Dextrose Agar with aureomycin as recommended by Cooke (6) for fungi. (Prior to 6-27-67,

acidified Potato Dextrose Agar was used).

SGPY agar: the above GPY with 0.2 gm of phenol added.

PGPY agar: the above GPY with 0.1 gm of phenol added.

YN agar: Nutrient Agar (DiFCO) with 3.0 gm/l. yeast extract added.

M agar: 1 gm non-fat dry milk, 15 gm agar, 100 ml. distilled water.

A portion of each of the above seven media except the ND is poured into sterile petri dishes to provide a semi-solid surface on which an inoculum could be streaked. These are "streak plates."

GPY agar plates are prepared in advance with a depression created in the agar before it is hardened by floating sterile, latex rings or loops in it and removing them aseptically after the agar hardened. This leaves a shallow trough sufficient to accommodate 0.1 ml. of inoculum. These are "loop plates." The remainder of the media was refrigerated in flasks until needed for pour plates on the day of sampling at which time it was melted and then cooled to 44-46°C before use.

Prior to plating, the original sampling jugs are mixed well and 25 ml. aliquots of each are pipetted to sterile 50 ml. beakers (see fig. 18). From these beakers, a sterile inoculating loop is used to inoculate by streaking the six poured streak plates for each of the seven samples.

Samples No. 1, 2, 3, 4 and sometimes 5 (depending on solids' concentration) after being streaked as above are treated with Biosonik II High Intensity Ultrasonic Probe at 40% intensity for 30 seconds. Samples NO. 6 and 7 are never treated with the Biosonik II.

All samples are diluted (see table I) serially 1:10 and the procedures for plating as outlined in Standard Methods (4) are followed as nearly as possible. Portions of the undiluted samples No. 1, 2, 5, 6, and 7, after Biosonik II treatment, are heated in sterile test tubes at 70°C. for 30 minutes. GPY pour plates are made using this heated inoculum. The remainder of the plates are ordinary pour plates using 1 ml. inocula.

Incubation and Examination

Incubation for all but three TGB pour plates done on samples No. 1, 2, 5, 6 and 7 which are incubated at 35°C., is 20°C. for a period of 27 days. A humidifier is used to prevent excessive drying of the media. These plates are examined for filamentous growth after 3, 8, and 27 days of incubation, the total number of filamentous colonies counted and recorded. Subcultures of significant organisms are made for further study. The plates incubated at 35°C. are examined after 3 and 8 days of incubation and the total (filamentous and non-filamentous) place count are recorded.

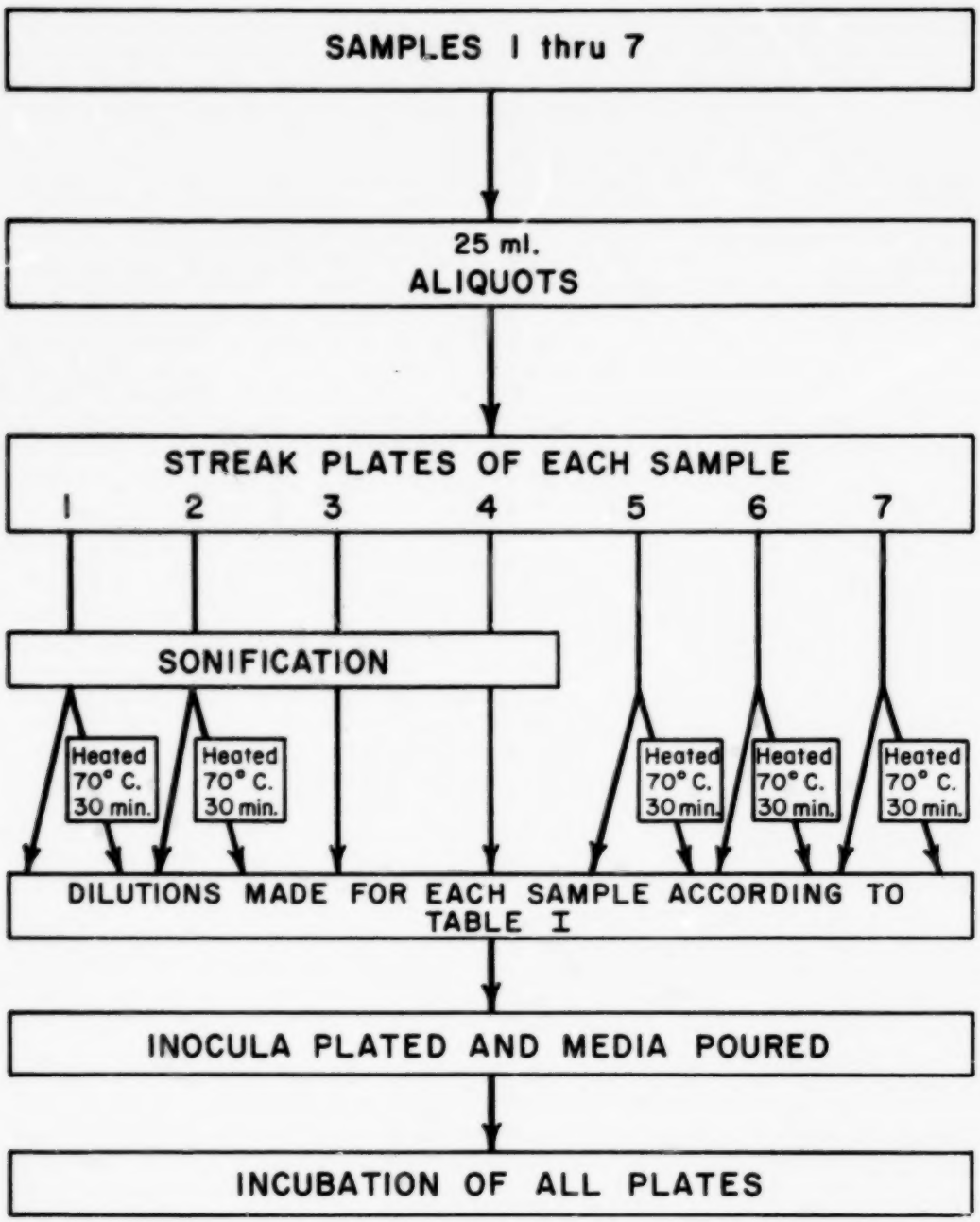

FIG. 18 - PROCEDURAL FLOW DIAGRAM FOR PLATING OF SAMPLES

TABLE I

DILUTIONS OF SAMPLES FOR PLATING

	Streak Plates	GPY heated Inocula Pour Plates	ND with Aureomycin Pour Plates	GPY		TGB	
				Loop Plates	Pour Plates	Pour Plates	Pour Plates 35°C.
Samples 1 & 2	Undiluted	$1:10^0$	$1:10^3$	$1:10^3$	$1:10^5$	$1:10^5$	$1:10^5$
		$1:10^1$	$1:10^4$	$1:10^4$	$1:10^6$	$1:10^6$	$1:10^6$
		$1:10^2$	$1:10^5$	$1:10^5$	$1:10^7$	$1:10^7$	$1:10^7$
Samples 3 & 4	Undiluted	----	$1:10^4$	$1:10^4$	$1:10^6$	$1:10^6$	----
		----	$1:10^5$	$1:10^5$	$1:10^7$	$1:10^7$	----
		----	$1:10^6$	$1:10^6$	$1:10^8$	$1:10^8$	----
Samples 5,6 & 7	Undiluted	$1:10^0$	$1:10^2$	$1:10^2$	----	$1:10^4$	$1:10^4$
		$1:10^1$	$1:10^3$	$1:10^3$	----	$1:10^5$	$1:10^5$
		$1:10^2$	$1:10^4$	$1:10^4$	----	$1:10^6$	$1:10^6$

DISCUSSION OF RESULTS

The results presented in this part are organized into sections as they relate to questions about operating problems of activated sludge processes. The questions discussed in these sections relate to 1) the types of operational problems found, 2) the types of filamentous organism present in the sludge examined, 3) the relationship between the presence of filamentous organisms and the types of sludge found, 4) the effect of the various problems on plant performance, and 5) the relationships between the environments in the activated sludge process and the development of operational problems.

Types of Sludge Examined

In a previous paper (5) the various types of activated sludge which separate poorly were described. The types of sludge which separate poorly due to adverse biological phenomena are bulking sludge, rising sludge, floating sludge, pin point floc, and deflocculated sludge. The types of sludge found in this project so far, in addition to normal sludge are bulking sludge, rising sludge, pin point floc, and deflocculated sludge.

Activated sludge which is normal in respect to its settling and compaction characteristics is defined in a negative manner; i.e., the absence of any type of separation problem. Normal sludge, when placed in a one liter cylinder, settles rapidly to the bottom and within thirty minutes will compact to a volume of less than 100 ml per gram. The supernatent above the sludge contains less than 30 mg/l of suspended solids. The sludge compacting on the bottom of the cylinder will remain on the bottom for at least eighteen hours.

A bulking sludge is one which compacts poorly and after thirty minutes in the cylinder has a volume of greater than 100 ml/gm. A S.I of between 100 and 300 ml/gm indicates a moderate bulking condition and a SVI of greater than 300 ml/gm indicates severe bulking.

Rising sludge, floating sludge, septic sludge, and overaerated sludge can be identified by the fact that they end up at the top of the cylinder instead of at the bottom. Floating sludge always stays at the top of the cylinder and cannot be caused to settle even by stirring. Overaerated sludge rises to the top of the cylinder at first but will settle to the bottom if stirred or sometimes even without stirring. Rising sludge settles initially but then rises to the top in a few hours or less. Septic sludge settles initially but after several hours turns black and then rises to the top. Both rising sludge and septic sludge can be broken up by stirring and will then settle back to the bottom.

Pin point floc and deflocculated sludge can be identified by an excessively high concentration of suspended solids in the supernatent above the settled sludge. In this project an excessively high concentration of supernatent suspended solids is defined 30 mg/l or greater. These two types of sludge can be differentiated on the basis of observation of the

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TABLE II

CLASSIFICATION OF SLUDGE TYPES FOUND

Trip No.	Plant Location	SVI (ml/gm) Sample 1	SVI (ml/gm) Sample 2	Supernatent S.S. (mg/l) Sample 1	Supernatent S.S. (mg/l) Sample 2	Classification
1	Carol Stream	46.5	47.7	65.5	64.1	Deflocculated
2	Crystal Lake	67.3	67.5	41.5	37.3	Pin Point Floc
3	West Chicago	92.1	94	55.0	51.2	Deflocculated
4	Fox River Grove	158.5	159	47.0	47.1	Deflocculated
5	West Chicago	77	78	34.8	28.7	Normal
6	Chicago, N. Side	125	114	32.5	24.8	Bulking
7	Ft. Wayne	346	378	14.3	18.3	Bulking
8	McHenry	78	76.9	28.8	27.7	Normal
9	Milton, Wisc.	65	99.2	54.2	47.5	Deflocculated
10	Brookfield, Wisc.	676	659	3.2	3.2	Bulking
11	Woodstock	38	75	68	50.4	Pin Point Floc
12	Gages Lake	189	168			Bulking & Rising
13	Libertyville	53	49	44.6	20.6	Pin Point Floc
14	Spinney Run	163	163	220	216	Deflocculated
15	Borden's Dairy	115	115	304	303	Deflocculated
16	Antioch, Ill.	73	85	121	98	Pin Point Floc
17	N. Shore, Clavey Rd.	43	45	60.7	63.3	Pin Point Floc
18	Gary, Ind.	274	340	very low		Bulking
19	Brookfield, Wisc.	161	146			Bulking & Rising
20	Spinney Run	59	60	11.1	10.9	Normal
21	Ft. Wayne	412	423	4.7	7.1	Bulking
22	Milton, Wisc.	148	155	61.6	36.5	Deflocculated
23	W. Chicago	224	260	23.8	21.2	Bulking
24	Libertyville	37	39	21.0	19.0	Normal
25	Woodstock	49	52	73.0	59.0	Pin Point Floc
26	Antioch, Ill.	57	52	40.0	32.0	Pin Point Floc
27	Gages Lake	145	148	37.0	43.0	Deflocculated
28	McHenry, Ill.	547	523	24.0	7.0	Bulking
29	Gary, Ind.	44	41	91.0	89.0	Deflocculated
30	Chicago, N.S.	81	80	44.0	49.0	Pin Point Floc

supernatent. Pin point floc is identifiable as small particles suspended in a clear liquid.

The SVI measurements and supernatent suspended solids determinations for the mixed liquor samples from the thirty sampling trips are presented in table II. On the basis of these data and the visual observation of the sludge settling in cylinders, the sludges are classified into types of separation problems. Undoubtedly the proportion of samples exhibiting separation problems is high due to the method of selecting plants for sampling. However, the general impression of sludge separation problems being common is probably correct.

A high supernatent suspended solids is considered to be a more serious sludge separation problem than a SVI in the range 100-300 ml/gm. There are known operational procedures for preventing the loss of sludge solids in the effluent when the only problem is a high SVI (7,8) but supernatent suspended solids are usually lost into the effluent. A number of the samples (from trips nos. 4, 14, 15, 22, and 27) which were classified as deflocculated due to a high concentration of very finely divided suspended solids in the supernatent could have been classified as moderate bulking due to the SVI values in the range 100-300 ml/gm. However, observations made at the time the samples were collected indicated that the sludge blanket in the secondary settling tank was low and that the solids which were being lost were the finely divided solids would not settle at all.

Pin point floc in the supernatent above the settled sludge is quite easy to identify visually. Of the thirty sets sampled, pin point floc was found in eight samples, all of which had low SVI values. Pin point floc appears to be a rather common separation problem.

Rising sludge was encountered only twice in the thirty sets of samples. In both cases it occurred in sludge samples with an SVI in the range 150-200 mg/l. Previously (5), it had been postulated that in order to rise, a sludge had to compact well. On the basis of these two samples, it is apparent that rising sludge can occur even in the case of moderate bulking. In both cases of rising sludge encountered, the sludge rose before the 90 minute settling time had elapsed, and it was not possible to obtain a supernatent sample for suspended solids determination.

The use of SVI and supernatent suspended solids as the sole means of classifying types of sludge separation problems is highly questionable. Both of these perameters are functions of the nature of the sludge itself, but the particular value measured for each is affected by a number of other factors. As a first attempt at classification of sludge types, SVI and supernatent suspended solids provide a starting point, but better techniques which would give measurement of sludge characteristics independent of the particular environment the sludge happens to occupy at the moment would permit better characterization of the phenomena involved in producing the sludge separation problems.

One of the factors which has a great effect on the value of SVI and supernatent suspended solids is the concentration of MLSS in the sample

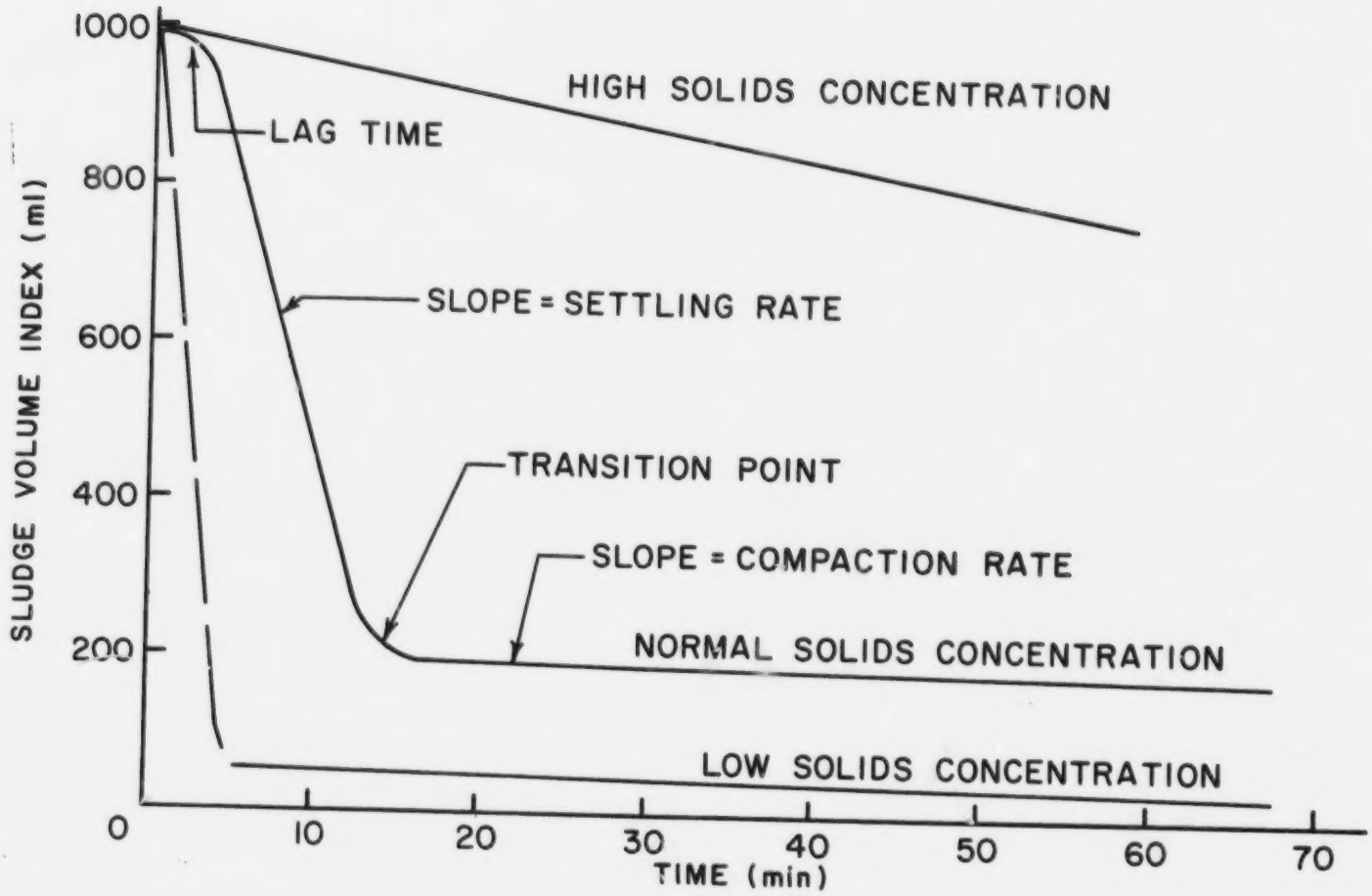

FIG. 19 - GENERALIZED SETTLING CURVES FOR ACTIVATED SLUDGE

before the settling test is started (2,3). In an effort to elucidate the effect of MLSS concentration on these perameters, a number of separate experiments were undertaken. The experiments involved collecting a sample of mixed liquor and varying the MLSS by concentrating some portions of the sample by settling and diluting other portions of the sample with supernatent from the concentrated portion. Suspended solids and settling tests were then made on the concentrated and diluted portions of the samples.

All of the samples tested in this manner gave similar results. When the sample was sufficiently diluted, the sludge particles settled independently forming a sludge mass at the bottom of the cylinder which then compacted. With the MLSS concentration in an intermediate range, the phenomena observed during the settling test were 1) a lag period before settling started, 2) formation of a distinct line of demarkation between the sludge surface and the supernatent with a rapid subsidence of the sludge surface, 3) a transition period, and 4) a period of compaction. When the sample was sufficiently concentrated initially, the only phenomenon observed was the slow compaction. These three types of responses to the settling test are illustrated in figure 19.

Although all three types of curves illustrated in figure 19 could be produced by dilution and concentration of any of the sludge samples tested, the MLSS at which each type of curve was produced varied a great deal from one type of sludge to another. With severly bulking sludge samples a settling curve showing only compaction was produced with an initial MLSS of less than 1000 mg/l while with normal sludges this type of curve was not produced until the initial MLSS was up to about 8000 mg/l.

Three sets of data from the dilution - concentration experiments on the special sludge samples are presented in figure 20. The curves fitted to these data show the effect of initial MLSS on the SVI. In the low solids range the SVI is constant at a relatively low value. In the intermediate solids range there is a change from low SVI to a higher SVI, but again the SVI will be constant over a range of solids concentrations. In the high solids range the SVI decreases as the initial MLSS increases due to the physical limit of 1000 ml for sludge volume. It should be pointed out that, in addition to the initial MLSS, such factors as temperature, D.O., violent mixing of sludge before the settling test, pH, etc. can have a great effect on the SVI of a sludge sample. In order to obtain data of the type presented in figure 20, it is necessary to be very careful to treat each diluted or concentrated portion of the sludge sample in exactly the same manner.

The physical characteristics of the sludges obtained during the thirty regular sampling trips are presented in tables III through VI. The values derived from analysis of settling curves were calculated in the manner indicated in figure 19. The values listed for the mixed liquor suspended solids and the settling curves are averages of the values from samples 1 and 2 except for three cases in which there was a large difference between samples 1 and 2. In these three cases the values in the tables are for sample 2 only.

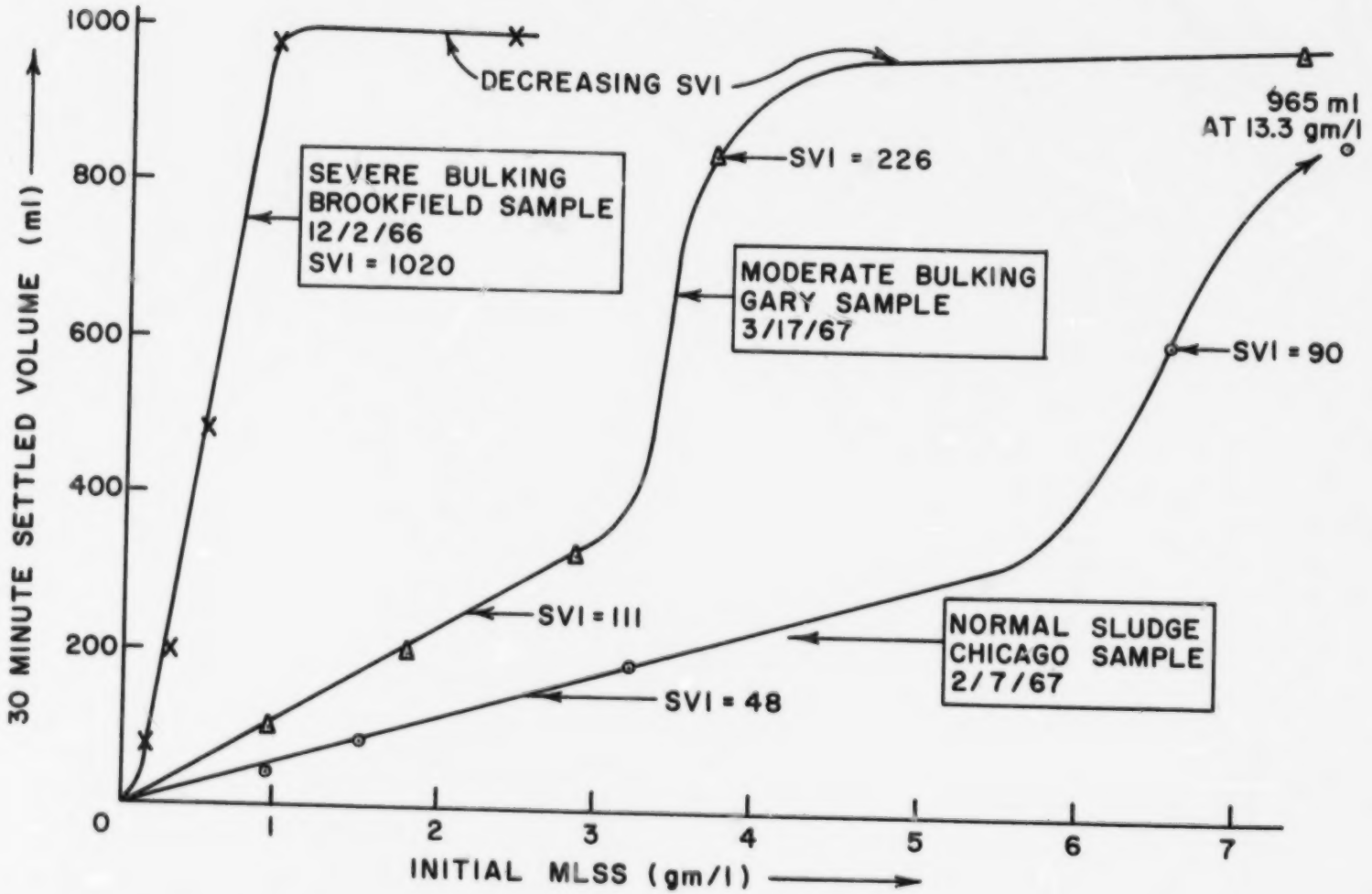

FIG. 20 - RELATION BETWEEN SVI AND MLSS FOR DIFFERENT SLUDGE TYPES

TABLE III

PHYSICAL CHARACTERISTICS OF NORMAL SLUDGE

Trip No.	Plant Location	Mixed Liquor Solids					Settling Curve			Return Sludge Solids		
		Total Suspended (mg/1)	Vol. Suspended (mg/1)	% Vol.	SVI (ml/gm)	Solids Range	Settling Rate (ml/min)	Trans. Conc. (mg/1)	Comp. Rate (ml/min)	Total Suspended (mg/1)	SVI (ml/gm)	Solids Range
5	West Chicago	2,446	1,602	65.5	78	low	226	8,150	0.45	4,310	189	inter-mediate
8	McHenry	4,416	3,164	71.9	77	low	60	10,720	1.14	9,472	102	inter-mediate
13	Liberty-ville	2,256	1,976	87.6	49	low	520	12,200	0.35	2,850	46	low
20	Spinney Run Farms	1,254	850	67.8	60	low	370	9,460	0.32	2,120	68	low
24	Liberty-ville	3,254	1,693	52.1	39	low	280	17,370	0.17	12,683	68	inter-mediate

TABLE IV

PHYSICAL CHARACTERISTICS OF SLUDGES WITH PIN POINT FLOC

Trip No.	Plant Location	Mixed Liquor Solids					Settling Curve			Return Sludge Solids		
		Total Suspended (mg/l)	Vol. Suspended (mg/l)	% Vol.	SVI (ml/gm)	Solids Range	Settling Rate (ml/min)	Trans. Conc. (mg/l)	Comp. Rate (ml/min)	Total Suspended (mg/l)	SVI (ml/gm)	Solids Range
2	Crystal Lake	1,186	1,039	87.6	68	low	600	8,495	0.09	2,909	111	inter-mediate
11	Woodstock*	3,481	2,406	69.1	75	low	80	10,540	0.64	5,327	86	low
16	Antioch	2,450	1,330	54.3	85	low	140	8,605	0.70	4,753	120	inter-mediate
17	Northshore Clavey Rd.	2,979	1,983	66.7	45	low	240	14,365	0.38	37,860	26	high
25	Woodstock	1,443	1,073	74.5	52	low	340	11,295	0.01	2,680	56	low
26	Antioch	5,004	2,674	53.4	52	low	210	12,870	0.72	9,460	82	inter-mediate
30	Chicago, Northside	2,736	1,936	70.8	80	low	315	8,225	0.67	9,600	99	inter-mediate

* Data from sample no. 2 only

TABLE V

PHYSICAL CHARACTERISTICS OF BULKING SLUDGES

Trip No.	Plant Location	Mixed Liquor Solids					Settling Curve			Return Sludge Solids		
		Total Suspended (mg/l)	Vol. Suspended (mg/l)	% Vol.	SVI (ml/gm)	Solids Range	Settling Rate (ml/min)	Trans. Conc. (mg/l)	Comp. Rate (ml/min)	Total Suspended (mg/l)	SVI (ml/gm)	Solids Range
6	Chicago Northside	2,659	1,688	63.4	114	low	87	6,360	1.25	8,250	118	low
7	Ft. Wayne	2,601	1,548	59.4	378	high	---	<2,601	2.34	5,207	188	high
10	Brookfield	925	890	96.3	659	high	29	1,452	2.1	1,825	537	high
12	Gages Lake	4,400	3,674	83.5	168	high	---	<4,400	3.5	4,733	170	high
1[illegible]	Gary	2,946	2,020	68.5	340	inter-mediate	26	6,075	2.2	7,383	135	high
19	Brookfield	1,188	805	67.8	146	low	285	4,320	0.49	3,510	252	inter-mediate
21	Ft. Wayne*	2,033	1,400	68.9	423	inter-mediate	7	2,710	3.9	10,693	94	high
23	West Chicago	2,570	2,007	78.0	260	inter-mediate	20	4,630	2.4	5,220	187	high
28	McHenry	1,644	966	58.1	523	high	---	<1,644	2.5	4,067	245	high

* Data from sample no. 2 only

TABLE VI

PHYSICAL CHARACTERISTICS OF DEFLOCCULATED SLUDGES

Trip No.	Plant Location	Mixed Liquor Solids					Settling Curve			Return Sludge Solids		
		Total Suspended (mg/l)	Vol. Suspended (mg/l)	% Vol.	SVI (ml/gm)	Solids Range	Settling Rate (ml/min)	Trans. Conc. (mg/l)	Comp. Rate (ml/min)	Total Suspended (mg/l)	SVI (ml/gm)	Solids Range
1	Carol Stream	3,418	2,263	66.4	48	low	160	15,540	0.41	11,690	81	inter-mediate
3	West Chicago	3,594	2,492	69.4	94	low	52	9,140	0.91	7,135	136	inter-mediate
4	Fox River Grove	1,732	1,063	61.4	159	inter-mediate	64	4,875	0.77	9,758	97	high
8	Milton*	605	461	76.2	99	low	880	5,550	0.11	415	72	low
14	Spinney Run Farms	980	998	100	163	low	352	3,380	0.77	1,213	160	low
15	Borden's Dairy	2,110	1,967	93.1	115	low	67	6,840	0.67	10,733	115	low
22	Milton	832	713	85.4	155	low	285	4,115	0.45	3,322	285	inter-mediate
27	Gages Lake	4,754	3,480	73.2	148	inter-mediate	9	7,925	2,3	5,650	153	inter-mediate
29	Gary	6,723	4,033	60.0	41	low	100	17,720	0.8	17,917	53	low

* Data from sample no. 2 only

Inspection of the data in these four tables lead to the following observations:

1. A high SVI is not necessarily associated with a high percent volatile matter in the MLSS, but the three samples with greater than 90% vol. matter all had SVI values greater than 100 ml/gm.
2. Three of the samples (from trips 2, 5, and 16) which had SVI values less than 100 ml/gm could have had SVI values greater than 100 ml/gm at increased MLSS concentrations which are still within the operating range for the activated sludge process.
3. Two samples (from trips 12 and 17) with SVI values greater than 100 probably would have had SVI values less than 100 ml/gm at MLSS concentrations around 1000 mg/l.
4. Pin point floc is produced only by sludge with SVI values less than 100 ml/gm.
5. Deflocculation occurs at SVI values less than 200 ml/gm.
6. All of the samples with SVI values less than 100 ml/gm have relatively similar settling curves except for the samples from trips 3, 8, and 11.
7. All of the samples with SVI values greater than 100 ml/gm had relatively similar settling curves except for the samples from trips 14, 19, and 22.

It is apparent that there are a large number of different phenomena which can interfere with the separation of activated sludge from effluent in the secondary settling tank. The use of SVI and supernatent suspended solids concentration, and visual observations of the sludge provides a starting place for description and classification of these phenomena. However, use of these characteristics as the sole criteria of separation problems results in the lumping together of some types of sludge which have demonstrably different settling characteristics. Additional physical characteristics of the various types of activated sludge need to be studied and related to plant performance.

Filamentous Organisms Present

The isolation of a particular organism from a particular sample of mixed liquor does not prove that the organism is playing a significant role in the activated sludge process. Additional evidence to demonstrate that the organism is present in large numbers, that it is present in a variety of activated sludge processes, that it is always associated with a particular condition, that it is able to grow in the environments of the activated sludge process, and that it has the ability to carry out a particular process in pure culture is needed to support the hypothesis of significance. In this project, the associations between particular filamentous organisms and sludge separation problems is being studied. The isolations and identifications which are being made are also being related to other evidence of the roles played by these filamentous organisms as it can be collected and assembled.

It is extremely difficult to obtain accurate counts on any of the filamentous organisms in activated sludge by any of the conventional plating techniques. Counts of fungi colonies on pour plates on potato-

TABLE VII

FILAMENTOUS ORGANISMS FOUND IN NORMAL SLUDGES

Trip No.	Plant Location	Yeast Count Colonies/gm.	Actino-mycetules	Bacillus	Sphaerotilus	Beggiatoa	Elongated Rods	Other	SVI
5	West Chicago	8,248	present	significant					76.6
8	McHenry	6,388	present	present	present				78.3
13	Liberty-ville	6,761	present	present					53.1
20	Spinney Run Farms	42,318	present	present					59.2
24	Liberty-ville	32,620	present	significant					36.5

TABLE VIII

FILAMENTOUS ORGANISMS FOUND IN SLUDGES WITH PIN POINT FLOC

Trip No.	Plant Location	Yeast Count Colonies/gm.	Actino-mycetules	Bacillus	Sphaerotilus	Beggiatoa	Elongated Rods	Other	SVI
2	Crystal Lake	16,116	present	present		present			67.3
11	Woodstock	9,203	present	present	present				38.2
16	Antioch	973	present	present					72.8
17	Northshore Clavey Rd.	32,949	present	present					42.6
25	Woodstock	7,062	significant	signifi-cant	significant				49.4
26	Antioch	2,476	present	signifi-cant		present			57.0
30	Chicago Northside	5,526	present	signifi-cant		significant	present		81.1

TABLE IX

FILAMENTOUS ORGANISMS FOUND IN BULKING SLUDGES

Trip No.	Plant Location	Yeast Count Colonies/gm.	Actino-mycetules	Bacillus	Sphaerotilus	Beggiatoa	Elongated Rods	Other	SVI
6	Chicago Northside	11,867	present	present		significant			125
7	Ft. Wayne	2,169	present	significant	present				346
10	Brookfield	5,094	present	present			significant		676
12	Gages Lake	3,756	significant	present					189
18	Gary	3,336	present	significant	present		present		274
19	Brookfield	3,308	present	significant	present				161
21	Ft. Wayne	2,652	present	significant					412
23	West Chicago	17,293	present	significant				no. 95	224
28	McHenry	13,432	present	present	significant				547

TABLE X

FILAMENTOUS ORGANISMS FOUND IN DEFLOCCULATED SLUDGES

Trip No.	Plant Location	Yeast Count Colonies/gm.	Actino-mycetules	Bacillus	Sphaerotilus	Beggiatoa	Elongated Rods	Other	SVI
1	Carol Stream	2,421	significant	present					46.5
3	West Chicago	8,248	present	present				no. 95	92
4	Fox River Grove	22,851	present	present					158.5
9	Milton	2,227	present	present		signifi-cant			65.4
14	Spinney Run Farms	19,101	present	signifi-cant		present	significant		163.2
15	Bordens	3,722	significant	present	present				114.5
22	Milton	9,094	present	present				slime	148
27	Gages Lake	1,993	significant	present			significant		145
29	Gary	286	present	signifi-cant		present	significant		43.8

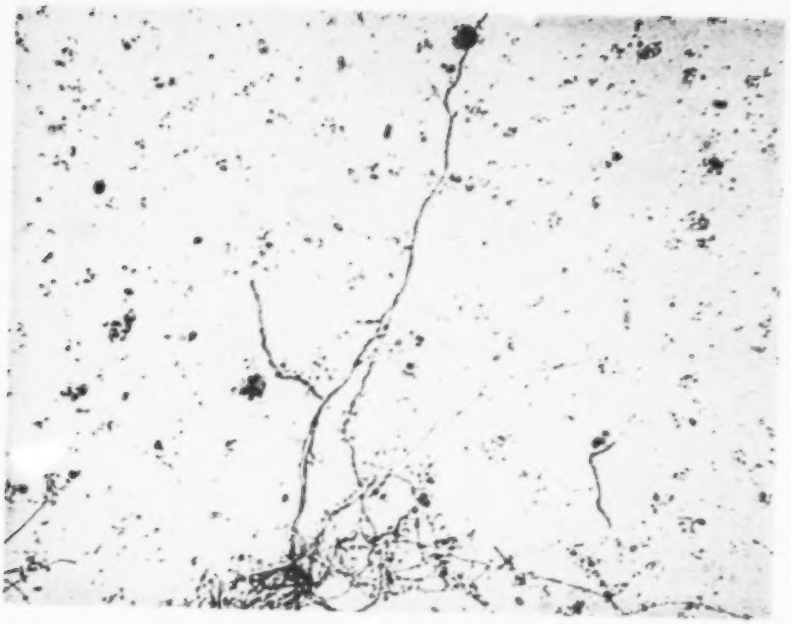

FIG. 21- PHOTOMICROGRAPH OF THE SLUDGE SAMPLE FROM FOX RIVER GROVE

dextrose agar or neopeptone-dextrose agar give relative numbers of these organisms in the sludge samples. Counts of single celled and filamentous yeasts should be fairly accurate providing that the cells are separated before plating and that all of the cells produce colonies on the plates. However, mold counts are unreliable because of the possibility of mycelial fragmentation during plating and the possible presence of large numbers of spores which are not growing in the sludge.

Actinomycetes and filamentous members of the genus Bacillus were found to be present in all of the sludge samples examined. They always showed up on the pour plates of the heated samples. These results are just about equivalent to finding these organisms in soil samples; their presence could be predicted a priori.

The other filamentous organisms found in these samples showed up only on streak plates or loop dilution plates. For these organisms it is possible to state only that there were many colonies or few colonies.

Because of the difficulty of obtaining any accurate counts of filamentous microorganisms in activated sludge, it is necessary to resort to subjective judgement to estimate significance of particular organisms in a particular samples. The criteria upon which these judgments were based are: 1) similarity between the appearance of the filaments in the sludge and the organisms in pure culture, 2) the extent of growth and the numbers of colonies appearing on the streak and loop plates, 3) the presence of the particular organisms in the sludge compared to its presence in the influent sewage, and 4) information from the literature that the particular organism is able to grow in environments similar to that of the activated sludge process.

The types of filamentous organisms found in the various sludge samples are tabulated in tables VII through X. The yeasts in this tabulation include Geotrichum, Trichosporon, Candida, Rhodotorula and other fungi which produce blastospores, arthrospores, or both. Several other types of fungi were found in various sludge samples. The sludge from trip 3 (figure 21) was composed mostly of a variety of yeast-like fungi and dispersed bacterial cells. None of the other cases of bulking contained any large numbers of fungi (other than the filamentous yeasts), and the data on fungi in activated sludge will be reported elsewhere.

All of the actinomycetes colonies counted appeared to be Nocaidia. However, only a few of these colonies were picked for pure culture studies, and it is possible that some of the colonies were Streptomyces.

The filamentous members of the genus Bacillus listed in these tables include Bacillus cereus, Bacillus cereus var. mycoides and Bacillus subitilus. Each of the samples of bulking sludge which had significant numbers of Bacillus had at least two of these species and no particular pattern of species compatibility was recognized. Thus the particular species are not separated in the listings. Figure 22 is a photomicrograph of one of the sludge samples in which Bacillus cereus was the predominant filamentous organism and figure 23 is a photomicrograph of a colony of the same organism growing on an agar plate.

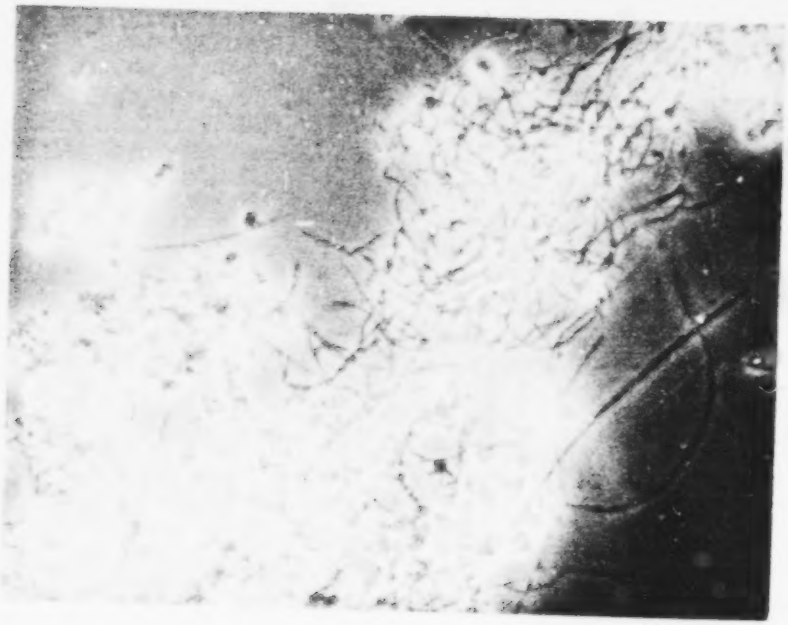

FIG. 22 - BACILLUS CEREUS IN ACTIVATED SLUDGE SAMPLE

FIG. 23 - BACILLUS CEREUS GROWING ON GPY AGAR PLATE

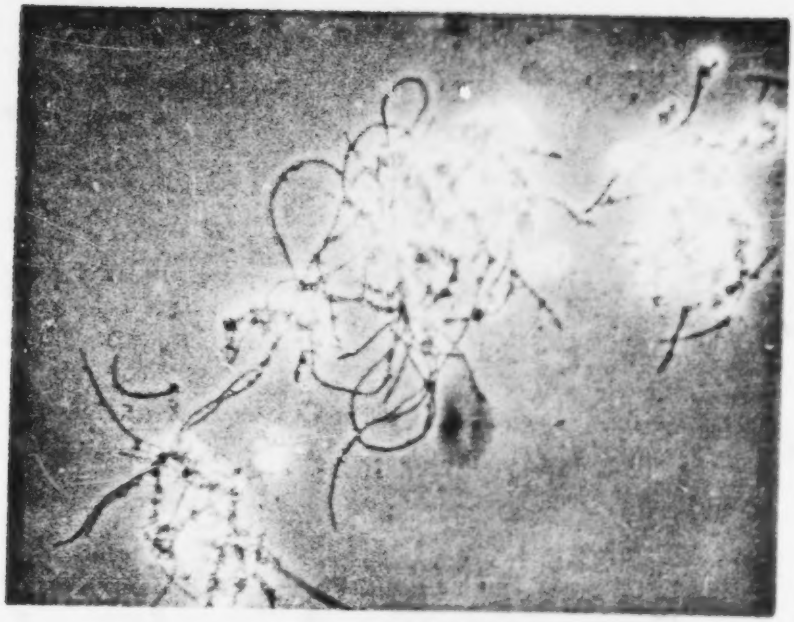

FIG. 24 - SPHAEROTILUS IN ACTIVATED SLUDGE

FIG. 25 - SPHAEROTILUS COLONY ON SURFACE OF AGAR PLATE

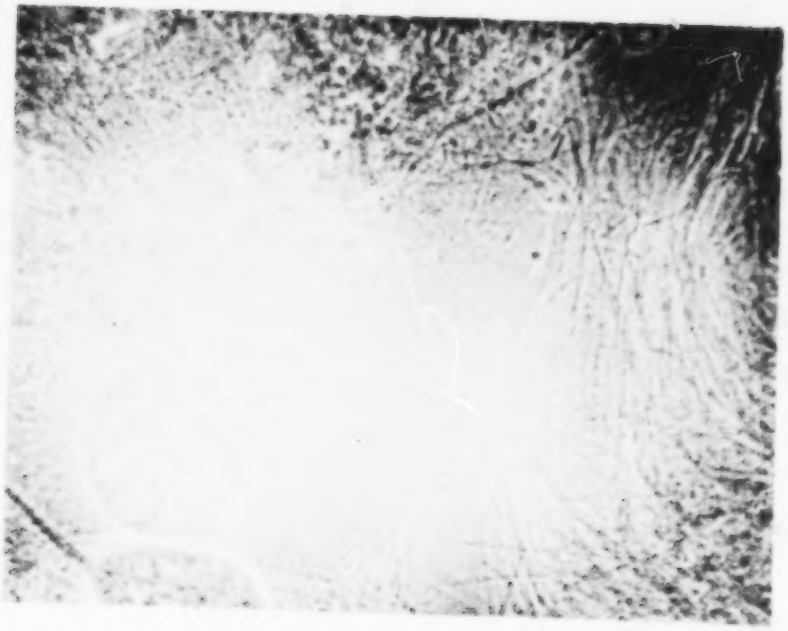

FIG. 26 - BEGGIATOA IN ACTIVATED SLUDGE

FIG. 27 - BEGGIATOA COLONY ON SURFACE OF AGAR PLATE

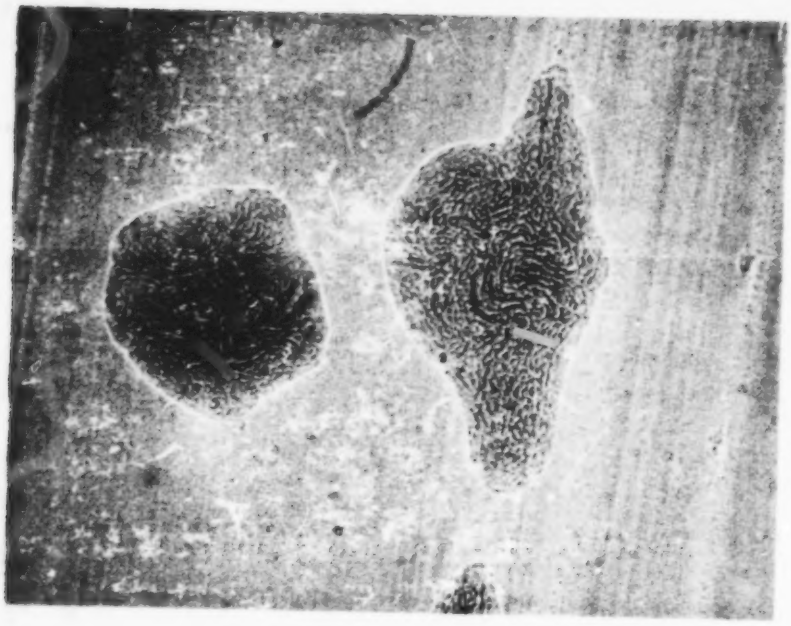

FIG. 28-"BRAIN" COLONY ON SURFACE OF AGAR PLATE

FIG. 29-"ELONGATED RODS" IN LIQUID CULTURE

FIG. 30-"SLIME" GROWTH FROM SLUDGE FROM TRIP 22 (MILTON, WISCONSIN)

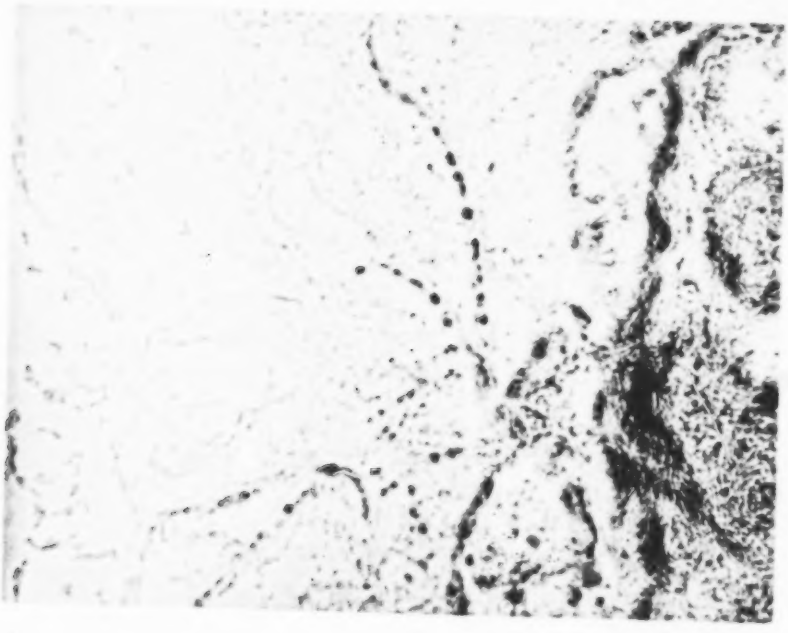

FIG. 31-SPHAEROTILUS - LIKE FLOCCULANT ORGANISMS FROM WEST CHICAGO PLANT

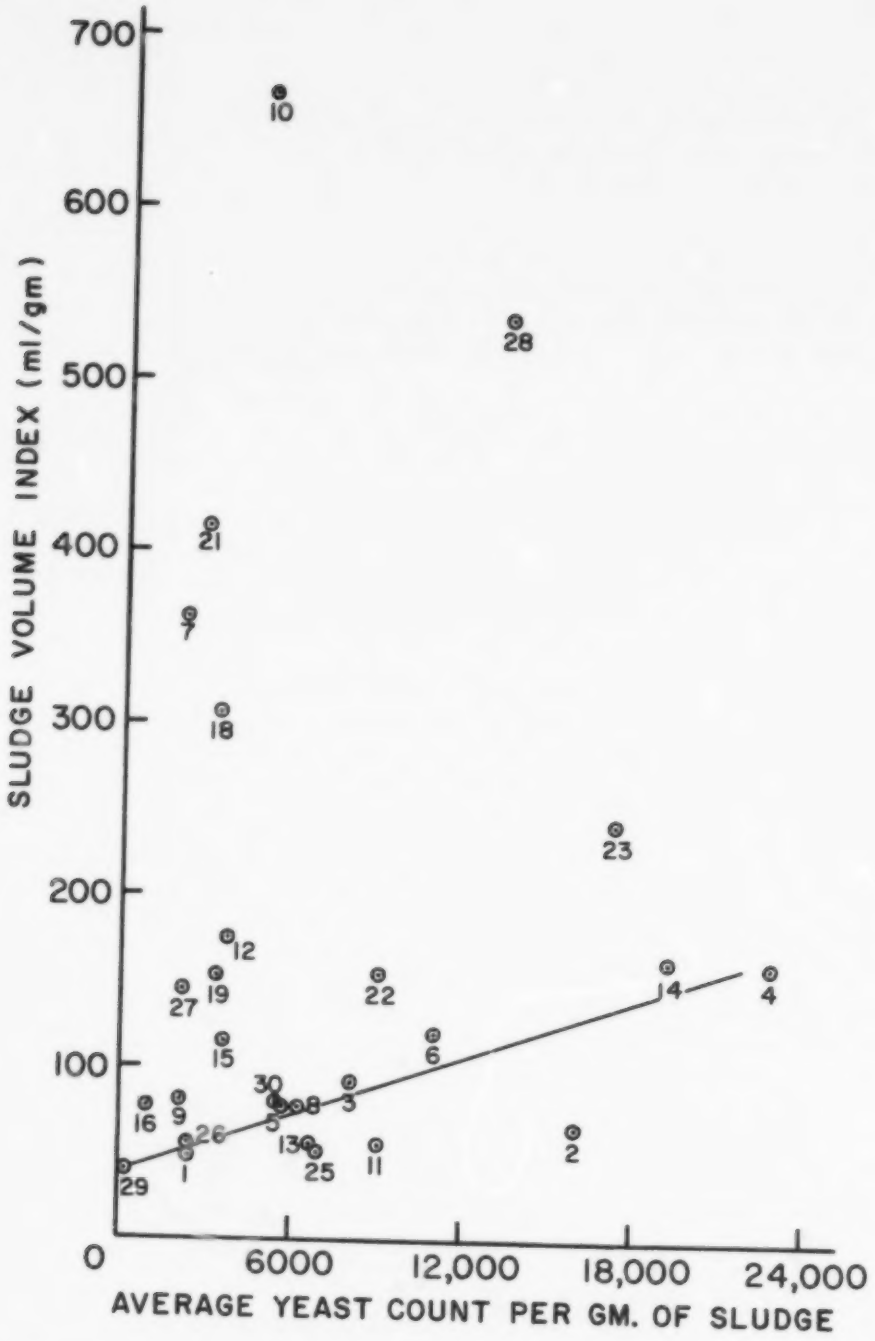

FIG. 32 - RELATIONSHIP BETWEEN SVI AND YEAST COUNT FOR SOME SLUDGE SAMPLES

The organisms listed as Sphaerotilus and Beggiatoa are extremely difficult to differentiate in the sludge and on the surface of agar plates, as illustrated in figures 24 through 27. These genera were differentiated on the basis of motility and straining reactions. Sphaerotilus cells isolated from the sheath are motile by means of polar flagella which can be demonstrated by flagella stains. Beggiatoa reacts negatively to the spore stain, but shows gilding motility in liquid cultures and sometimes on the surface of agar plates.

One other filamentous bacterium was found in large numbers in four different sludge samples. This organism has not yet been identified, and is indicated in the table as elongated rods. On the surface of an agar plate, it grows in convolutions resembling those of a brain (figure 28); and in pure culture it grows as elongated rods (figure 29).

One organism which spread as slime over the surface of agar plates was found a few times, but considered significant only in the sample from trip 22. This organism is illustrated in figure 30.

An organism which appears to be very similar to Sphaerotilus, except that it is covered with a mucilageous mass and grows as floc particles, was isolated twice, each time from a sludge sample from the West Chicago plant. This organism is labeled as culture no. 95, and is illustrated in figure 31.

As stated previously, none of the molds appeared to have any significant association with any of the sludge separation problems, except for the sample collected on trip no. 3. On the other hand, the yeasts do appear to be associated with some type of compaction problems. The data plotted on figure 32 indicate that the SVI values for sludges from trips no. 29, 16, 9, 1, 26, 30, 5, 8, 13, 25, 11, 3, 4, 6, and 14 are proportional to the average count of yeast colonies per gm of sludge. On this basis the SVI values of samples from trips no. 6, 4 and 14 could be greater than 100 ml/gm due to excessive numbers of yeasts. All of the data points above the line represent samples in which were found large numbers of filamentous bacteria. The data points below the line represent samples from trips no. 2, 17 and 20 are definitely below the line, the latter two being so high in yeast count that they do not fit the scale plotted.

Actinomycetes were present in all sludge samples examined, and usually gave plate counts of $10^{}$ - $10^{}$ per ml. of sample. In three samples (from trips no. 1, 12, 15, 25 and 27), the plate count of actinomycete population is considered to be significant.

Filamentous members of the genus Bacillus are found in all sludge samples and are present in significant numbers in 2 of the 5 normal sludge samples, 3 of the 7 samples with pin point floc, 5 of the 9 bulking sludge samples, and 2 of the 9 deflocculated sludges. Apparently filamentous members of the genus Bacillus can be present in large numbers in non-bulking sludges. However, these organisms were the only filamentous

organisms present in significant numbers in five samples of bulking sludge, and must be considered the causative organism in these cases.

Sphaerotilus was present in eight of the thirty samples examined, but was judged to be significant in only two. It can sometimes be isolated from samples with a low SVI. It apparently was the bulking organism in only one instance (trip no. 28).

Beggiatoa was found in samples from seven of the trips, and was judged to be significant in three of the samples. It is more frequently associated with deflocculation and pin point floc than with bulking.

The elongated rods were found in six samples. They were present in significant numbers in one of the bulking sludge samples and in three of the deflocculated sludges. In the one bulking sludge sample, they were the only filamentous microorganism whose presence was judged to be significant.

From these data, it is evident that no simple straightworward relationship between the presence of a particular filamentous organism and either bulking, deflocculation, or pin point floc can be demonstrated. However, if it is assumed that the excessive numbers of filamentous organisms do retard settling and compaction of activated sludge, then it is possible to select the organism responsible for bulking in each case. Of the nine samples classified as bulking, 5 were cases of Bacillus bulking, 2 cases (from the same plant) were actinomycete bulking, one case was Sphaerotilus bulking, one was due to the elongated rods, and one to yeasts. It is interesting to note that in all cases of bulking in which the SVI was greater than 200 ml/gm, the supernatent suspended solids were extremely low. Of the seven cases of deflocculated sludge in which the SVI was between 100 and 200 ml/gm, the high SVI was due to yeasts in two cases, Beggiatoa in three cases, and elongated rods in two cases.

Filamentous Organisms and Sludge Characteristics

Although the relationship between the numbers of filamentous organisms and the SVI of a sludge sample can not be demonstrated on the basis of a plate count technique, it can be demonstrated from the data on the microscopic count of filaments on the sludge particles. Figure 33, in which the total number of filaments counted per milligram of MLSS is plotted versus the SVI in ml/gm, illustrates this relationship rather well. In this investigation the total numbers of filaments attached to sludge particles are being counted. Other data supporting the hypothesis that a high SVI is the result of an excessively high count of filamentous organisms in the sludge has been published previously (9) by Finstein and Heukelekian who were not only counting but also measuring total length of the filaments.

The microscopic counts of sludge particles and filaments are made by counting numbers of particles in eight size ranges, the unit size being $3906.25\mu^2$. Thus, particle sizes are evaluated on the basis of the projected planar area and not their diameter. The number of particles counted in each size range are then plotted on a histogram, and the number of

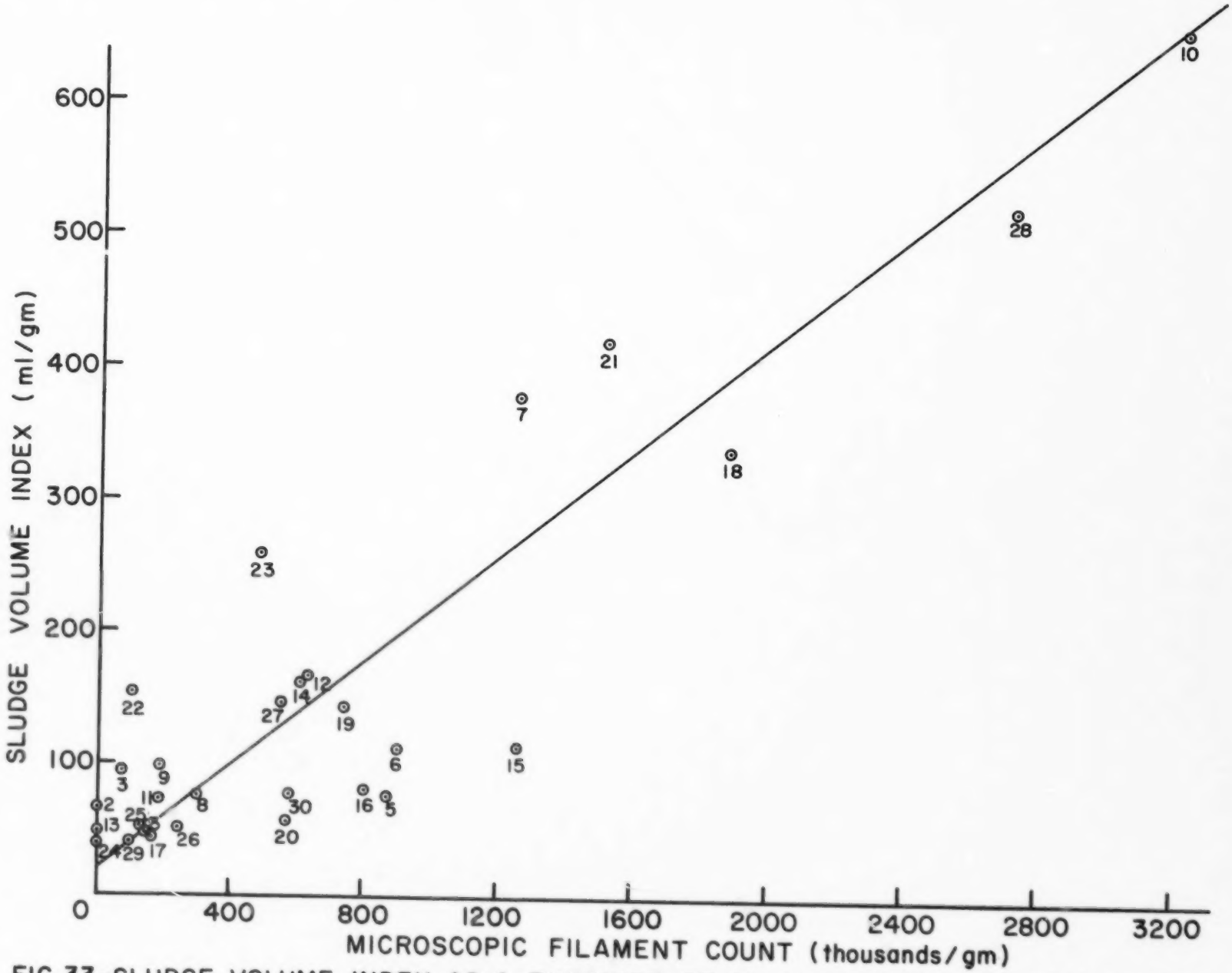

FIG.33-SLUDGE VOLUME INDEX AS A FUNCTION OF FILAMENTOUS ORGANISM COUNT

filaments counted on particles in each size range are noted on the histogram. An example of the type of histogram obtained in presented in figure 34.

The data are then translated from the histogram to a log probability plot an example of which is presented in figure 35. For most samples the data fit a straight line on the log probability plot indicating that the particle size distribution of activated sludge particles approximates a geometrically normal distribution. The sample from trip 4 had many extremely small particles and a few large fungus mycelia and did not fit this distribution. The samples from trips nos. 11, 14, 15 and 25 had mostly particles in the first size range and the numbers of larger particles were inadequate to determine if the data would fit a log probability plot or not. The samples from eleven other trips had over 50% of their particles in the first size range but enough particles in the higher size ranges so that the log probability plot could be made.

The filament counts are plotted on the log probability plot and these data also fit a straight line as indicated in figure 35. In most cases the line fitted to the filament data is parallel and to the left of the line fitted to the data on particle count as shown in figure 35. This indicates that a majority of the filaments are associated with the larger size particles. However, the data from the samples from trip numbers 7, 12, 18, 19, 21, 22, 23, and 27 gave convergent lines on the log probability plot as illustrated in figure 36. This indicates that the majority of the filaments were associated with the intermediate size particles. There are the samples which had significant numbers of actinomycetes or of filamentous members of the genus Bacillus.

The finding that usually the filamentous organisms are associated with the larger size particles is not surprising. Filamentous organisms would be expected to expand the size of a floc particle by their outward growth. However, the finding that the majority of the actinomycete and Bacillus filaments are associated with the intermediate size particles is not expected. This observation could be explained on the supposition that although the filaments have a tendency to extend the particles by their manner of growth, when they are attached to a large particle, they have a tendency to be sheared off as the particle moves through the water; i.e., the momentum of the larger particles is sufficient to break off filaments by "whip-lash" action.

From the log probability plots of the data from the microscopic counts on the sludges, the geometric mean and geometric standard deviation of the particle size distribution can be determined. These derived data are presented in Tables XI - XIV along with some other data relating to the physical nature of the sludge particles.

A survey of the data in these tables indicates that normal sludges have a mean particle area between 28 and 68 μ^2 and relatively small standard deviations. The sludges with pin point floc have a much smaller mean particle area except for two samples. The bulking sludges with one exception have larger mean particle areas. Most of the deflocculated sludges have very small mean particle areas as might be expected. In

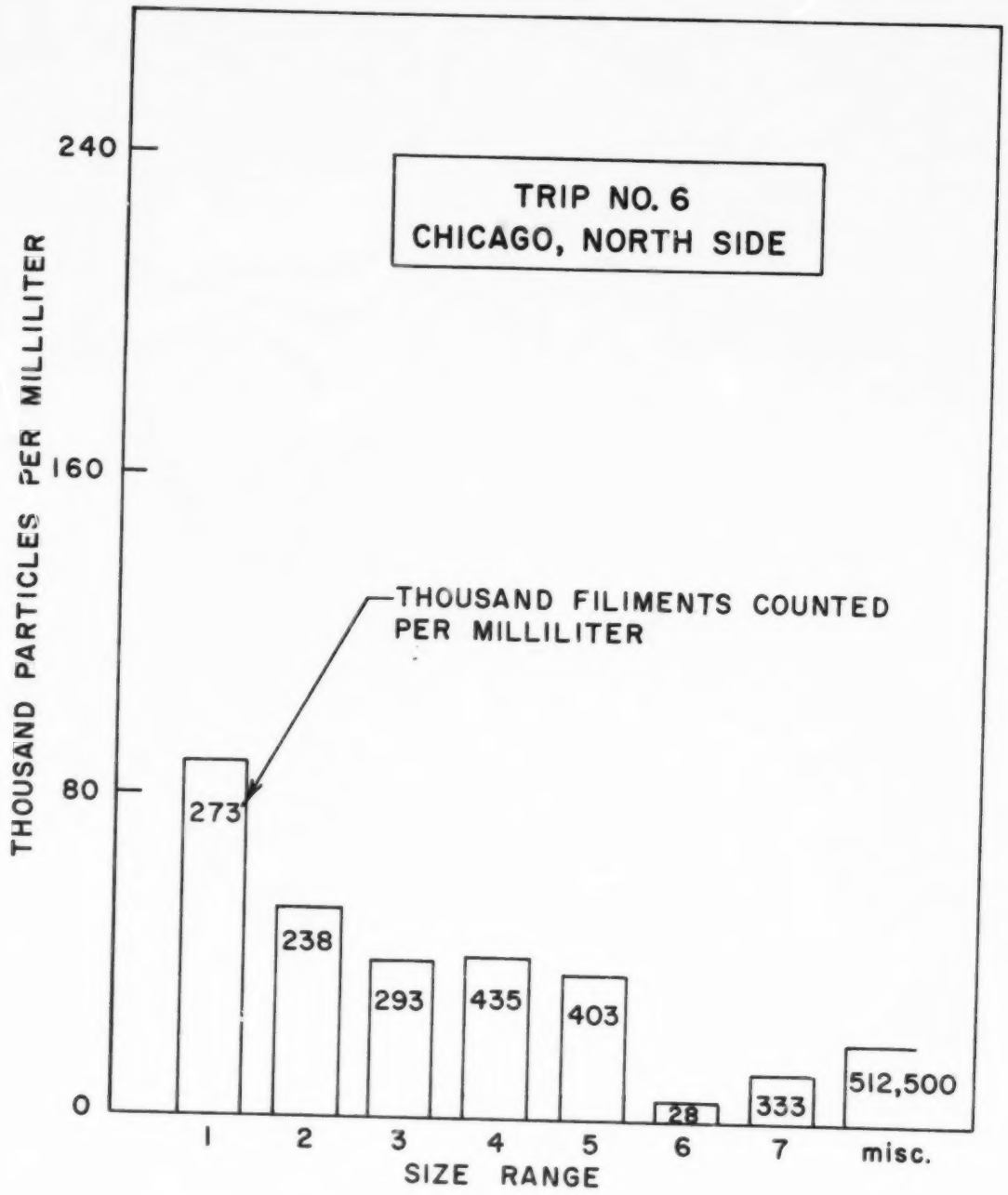

FIG. 34 - EXAMPLE HISTOGRAM OF SLUDGE PARTICLE COUNT DATA

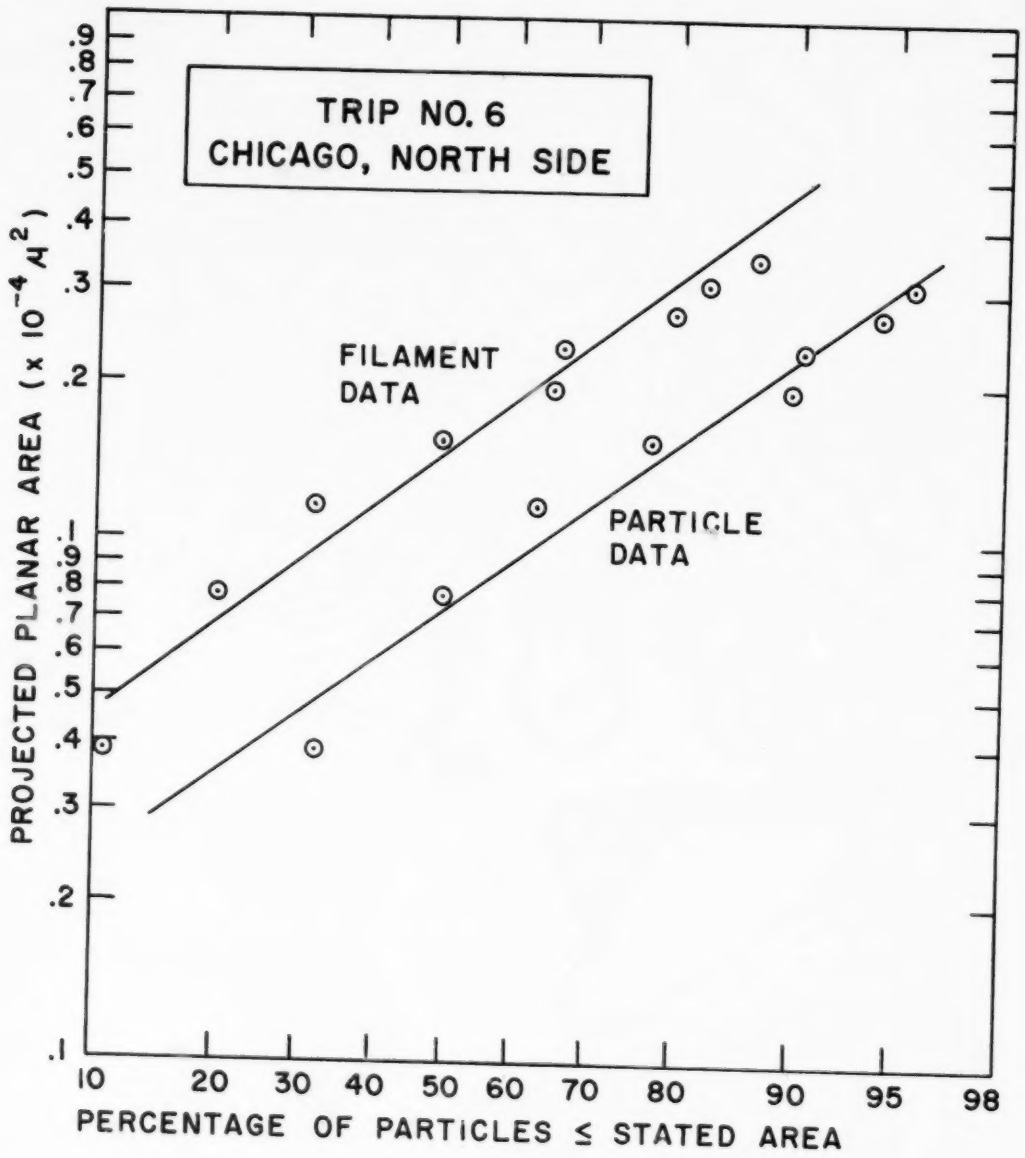

FIG. 35 - EXAMPLE PROBABILITY PLOT OF SLUDGE PARTICLE COUNT DATA

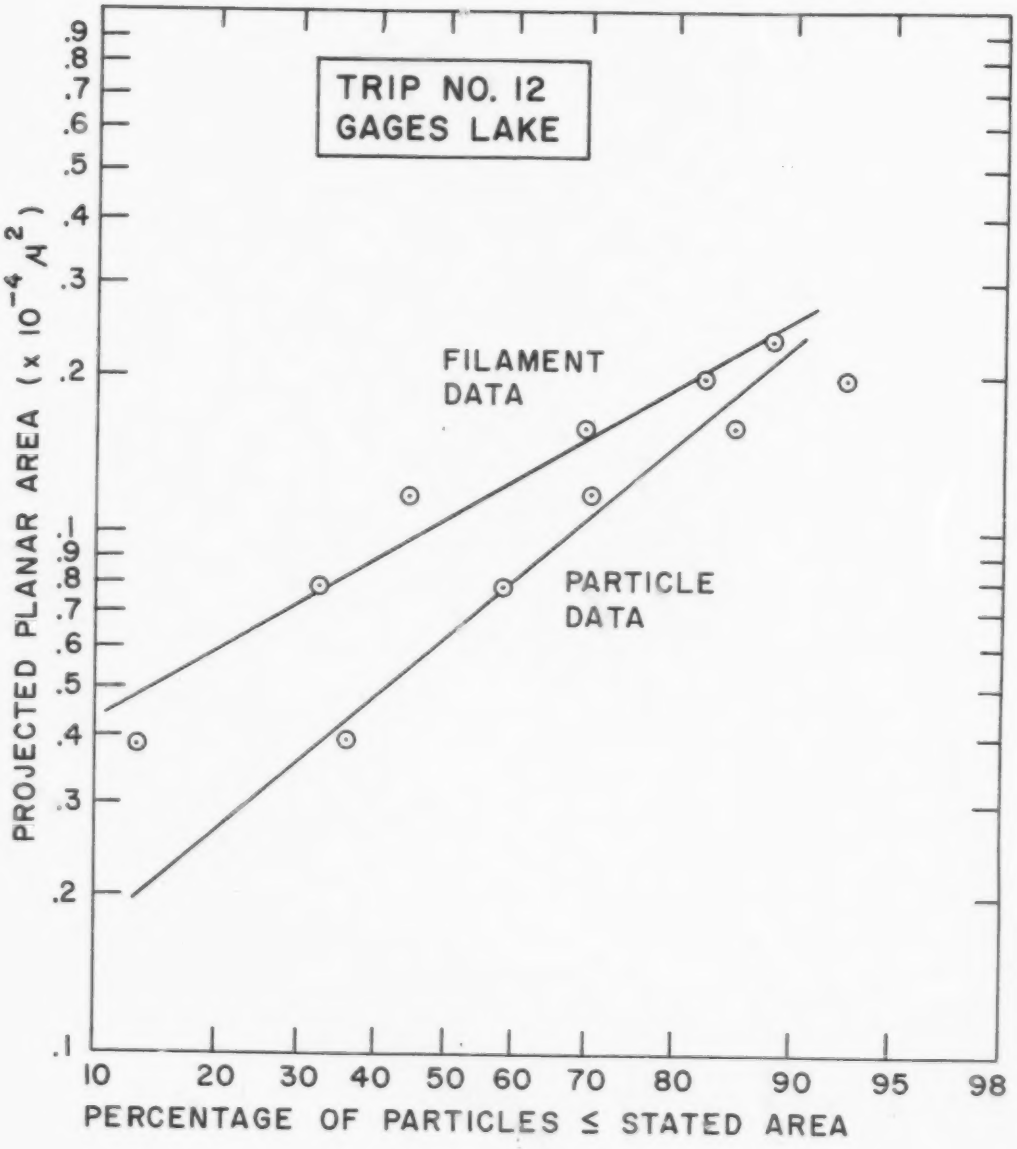

FIG. 36 - EXAMPLE PROBABILITY PLOT OF SLUDGE PARTICLE COUNT DATA

TABLE XI

PARTICLE CHARACTERISTICS OF NORMAL SLUDGES

Trip No.	Plant Location	Projected Particle Area		Total Particles (per ml)	MLSS (mg/l)	SVI (ml/gm)	Settling Rate (ml/min)	Total Filaments (per ml)
		Geometric Mean μ^2	Geometric Standard Deviation					
5	West Chicago	6,800	2.4	347,500	2,446	78	226	2,208,000
8	McHenry	6,100	2.3	522,100	4,416	77	60	1,344,900
13	Libertyville	3,800	2.7	641,100	2,256	49	520	5,640
20	Spinney Run Farms	2,900	3.6	281,300	1,254	60	370	703,800
24	Libertyville	2,800	3.1	555,000	3,254	39	280	18,800

TABLE XII

PARTICLE CHARACTERISTICS OF SLUDGES WITH PIN POINT FLOC

Trip No.	Plant Location	Projected Particle Area		Total Particles (per ml)	MLSS (mg/l)	SVI (ml/gm)	Settling Rate (ml/min)	Total Filaments (per ml)
		Geometric Mean μ^2	Geometric Standard Deviation					
2	Crystal Lake	5,300	8.3	76,000	1,186	68	600	10,000
11	Woodstock	<<3,900	---	7,099,000	3,481	75	80	674,000
16	Antioch	1,800	3.8	1,106,200	2,450	85	140	1,956,000
17	Northshore Clavey Rd.	3,600	3.1	527,500	2,979	45	240	497,500
25	Woodstock	<<3,900	---	805,000	1,443	52	340	170,000
26	Antioch	3,000	2.7	1,640,500	5,004	52	210	1,209,400
30	Chicago Northside	10,000	2.4	225,000	2,736	80	315	1,485,000

TABLE XIII

PARTICLE CHARACTERISTICS OF BULKING SLUDGES

Trip No.	Plant Location	Projected Particle Area		Total Particles (per ml)	MLSS (mg/l)	SVI (ml/gm)	Settling Rate (ml/min)	Total Filaments (per ml)
		Geometric Mean μ^2	Geometric Standard Deviation					
6	Chicago Northside	7,200	2.6	310,000	2,659	114	87	2,514,500
7	Ft. Wayne	6,200	8.0	127,500	2,601	378	---	3,112,200
10	Brookfield	5,800	2.8	270,000	925	659	29	3,093,000
12	Gages Lake	6,100	3.0	615,000	4,400	168	---	3,011,000
18	Gary	1,600	3.2	3,118,200	2,946	340	26	5,179,000
19	Brookfield	6,200	2.7	215,000	1,188	146	285	857,500
21	Ft. Wayne	5,900	5.3	352,500	2,033	423	7	3,084,600
23	West Chicago	4,800	2.5	497,500	2,570	260	20	1,247,500
28	McHenry	3,600	3.0	750,000	1,644	523	---	4,467,500

TABLE XIV

PARTICLE CHARACTERISTICS OF DEFLOCCULATED SLUDGES

Trip No.	Plant Location	Projected Particle Area		Total Particles (per ml)	MLSS (mg/l)	SVI (ml/gm)	Settling Rate (ml/min)	Total Filaments (per ml)
		Geometric Mean μ^2	Geometric Standard Deviation					
1	Carol Stream	5,900	2.9	380,100	3,418	48	160	511,800
3	West Chicago	4,900	2.8	617,500	3,594	94	52	259,500
4	Fox River Grove	T N T C			1,732	159	64	TNTC
9	Milton	3,300	3.2	35,900	605	99	880	TNTC
14	Spinney Run Farms	<<3,900	---	486,800	980	163	352	76,100
15	Borden's Dairy	<<3,900	---	1,868,700	2,110	115	67	2,681,200
22	Milton	3,000	9.0	47,300	832	155	285	94,200
27	Gages Lake	5,500	2.6	787,500	4,754	148	9	2,571,900
29	Gary	1,900	3.7	2,044,000	6,723	41	100	630,000

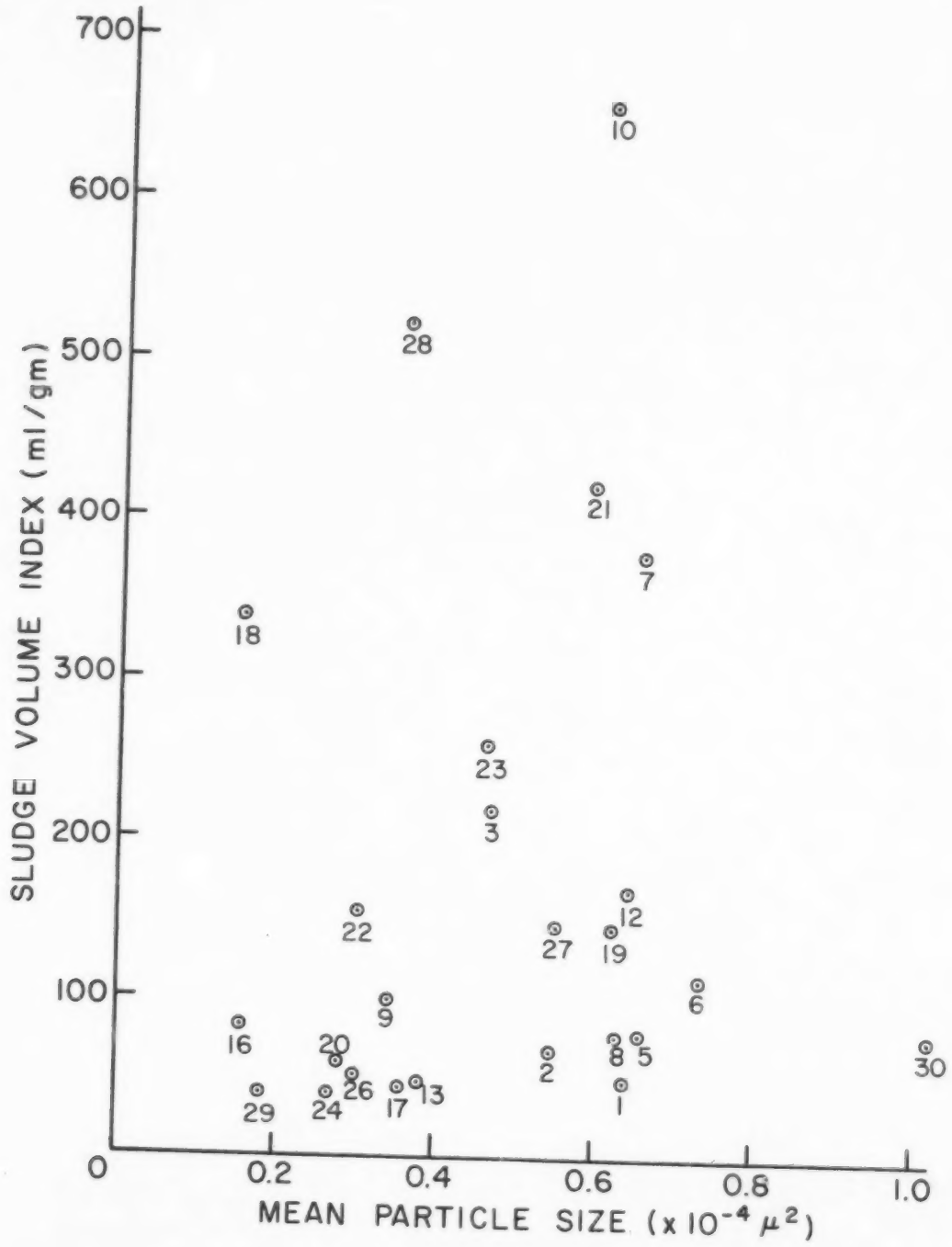

FIG. 37-LACK OF RELATIONSHIP BETWEEN SLUDGE VOLUME INDEX AND MEAN PARTICLE SIZE

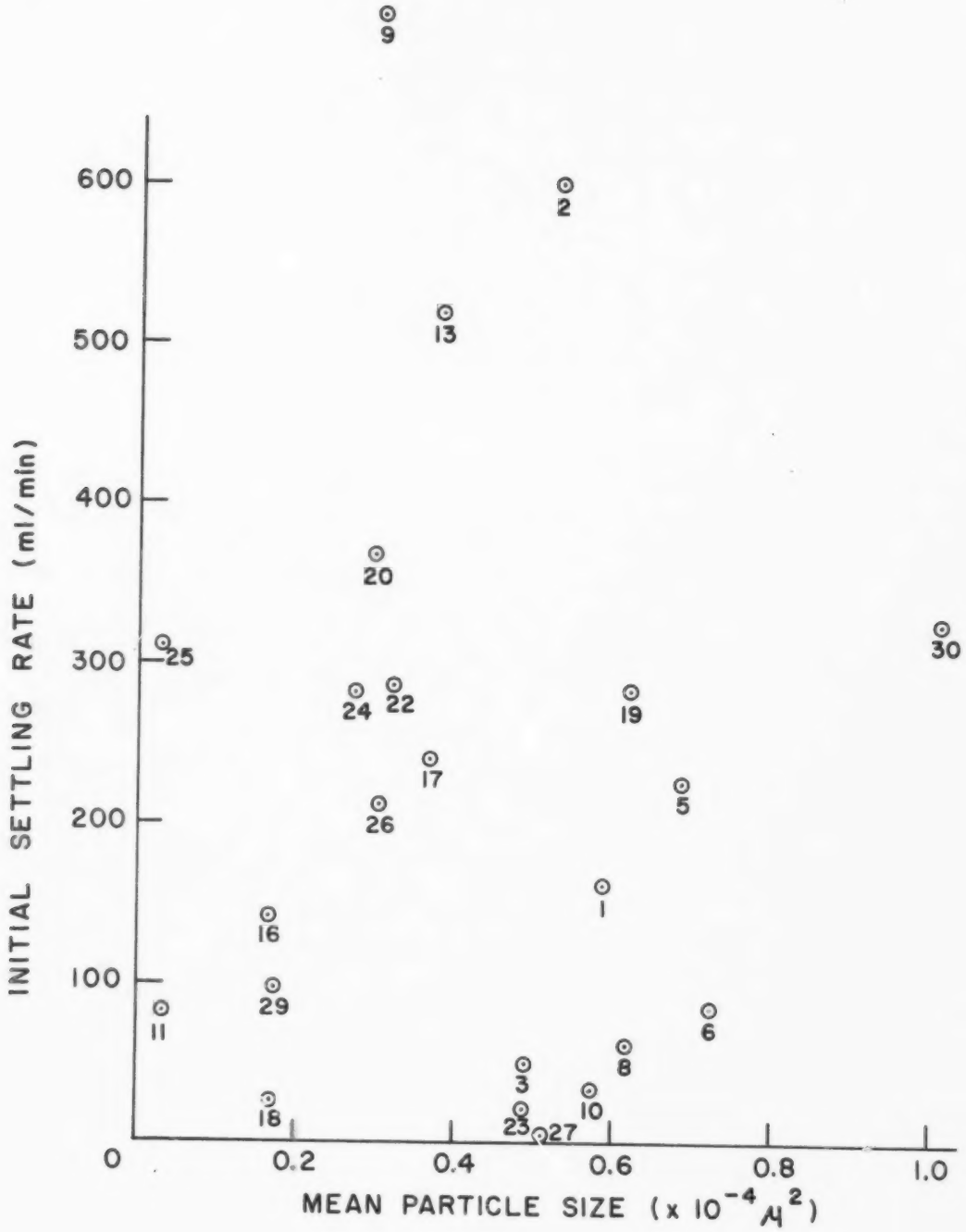

FIG. 38-LACK OF RELATIONSHIP BETWEEN SETTLING RATE AND MEAN PARTICLE SIZE

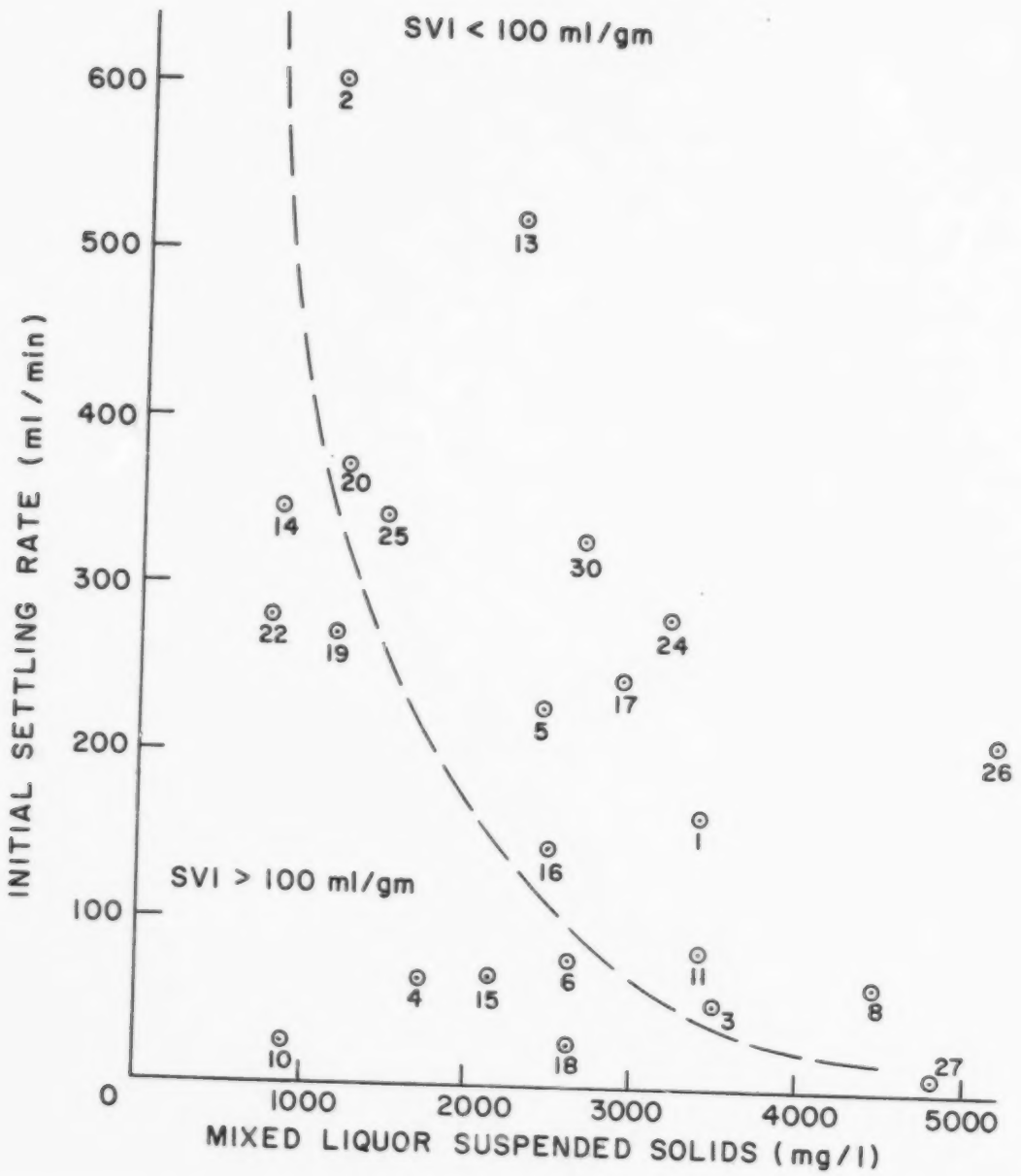

FIG.39-DIVISION BETWEEN SETTLING RATES OF BULKING AND NON-BULKING SLUDGES

some cases the mean particle sizes of deflocculated sludge samples would have been much smaller if individual bacterial cells and flagellated protozoans had been included in the count.

On the basis of what is known about the settling and compaction of inorganic particles in water, it would be expected that the particle size distribution of activated sludge particles should bave a large influence on these properties. However, on the basis of data collected so far, no direct relationship is apparent. The data plotted in figures 37 and 38 show a great deal of scatter and do not indicate any direct relationship between the mean particle area and either the sludge volume index or the initial settling velocity. The lack of any apparent relationship in these figures is probably due to the effect of other factors which have not yet been identified and taken into account.

It would also be expected that there would be a relationship between mixed liquor suspended solids and the initial settling velocity of the sludge. These factors are plotted on figure 39. It is apparent from this graph that generally the higher the MLSS, the lower the initial settling velocity. Sludge volume index also has a relationship to the initial settling velocity. The dashed line of figure 39 separates the samples which had SVI values greater than 100 from those which had SVI values less than 100. Obviously, the sludges with higher SVI values have lower initial settling velocity than those with lower SVI values.

Another method of presenting the information contained in figures 33 and 39 is to plot the initial settling velocity versus the microscopic count of filaments per gram of sludge. This had been done on figure 40. It is obvious that there is a decrease in the initial settling velocity as the number of filaments in the sludge increases.

By the data presented in this section it is shown that an increase in the numbers of filaments in activated sludge is associated with an increase in the sludge volume index and the initial settling rate of the sludge. Thus it is possible to state that bulking is the result of a change in the macroscopic physical characteristics of the sludge due to the presence of excessive numbers of filamentous organisms in the sludge. There does not appear to be any distinction between the effects of different types of filamentous microorganisms on the sludge characteristics.

Performance of Processes Sampled

The performance of an activated sludge process should be evaluated on the basis of the quality of effluent which is produced. Also it should be evaluated over a period of time in order to minimize the effect of random fluctuations in effluent quality. With the grab samples used for this project, it is not possible to make an evaluation of overall plant performance. However, it is possible to draw some conclusions about the correlation of various measurements on the effluent samples obtained.

The quality of effluent from a biological waste treatment operation has traditionally been evaluated in terms of the BOD and suspended solids

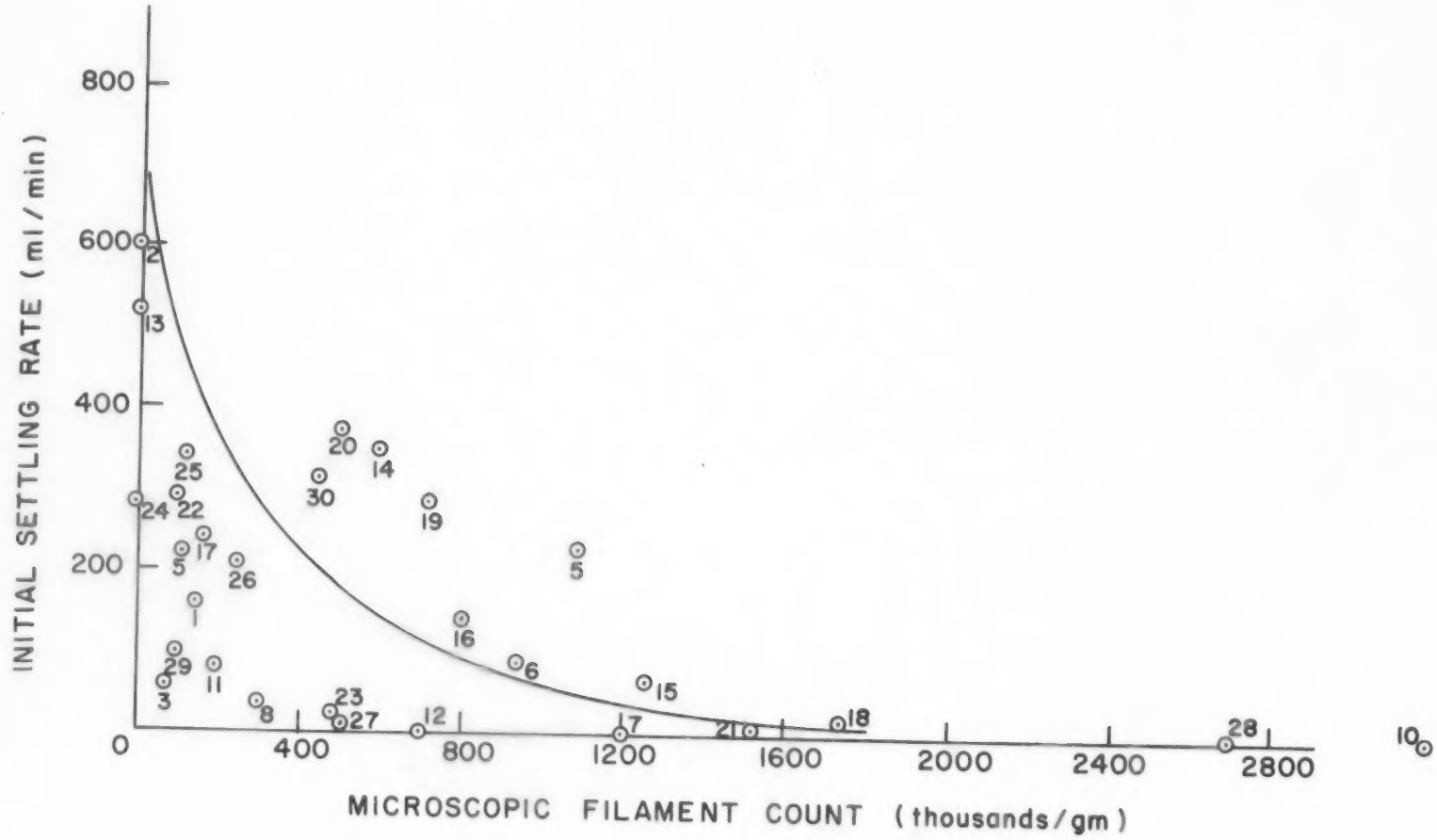

FIG. 40 - INFLUENCE OF FILAMENTS ON SETTLING RATE OF ACTIVATED SLUDGE

concentration. These data for the thirty sampling trips included in this report are presented in Table XV. It is apparent from these data that the production of a good quality effluent by an activated sludge process requires good solids separation.

The measurements of the effluent BOD values and suspended solids concentrations are plotted in figure 41. Twenty-six of the thirty points were used for a least squares analysis to determine a line of best fit. The equation of this line is given on figure 41. For these twenty-six points there is a good correlation between effluent BOD and suspended solids concentration. From this relationship it may be inferred that the solids in the effluent contain activated sludge organisms which consume large amounts of oxygen by their respiratory activities and that, in many cases, the effluent BOD represents this respiratory oxygen consumption by sludge organisms.

The effluent sample from trip no. 4 contained so high a concentration of suspended solids that it did not fit the scale for figure 40, but it still had a BOD of 30.7 mg/l. The plant was receiving wastes from metal finishing operations and much of the suspended matter in the effluent was a finely divided inorganic precipitate.

The sample from trip no. 15 also had a much, much higher concentration of suspended solids than BOD in the effluent. The influent BOD for this trip was also much lower than could be reasonably expected. Since these samples were obtained from a plant treating only dairy wastes, the obvious explanation is that some disinfectant from the wash operations was present in both the influent and effluent at the time of sampling and that the BOD values determined are inaccurate.

The sample from trip no. 14 was also obtained from a plant treating only dairy wastes. The effluent BOD was 1020 mg/l with a suspended solids concentration of 632 mg/l. These values fit the equation of figure 40 but are off the scale used.

The effluent sample from trip no. 8 had a BOD value more than twice the suspended solids concentration. This plant received a large amount of molasses from an accidental spill in a local industry the day before the samples were obtained. In a situation of this type, a large amount of soluble BOD can pass through the activated sludge process.

Taken as a group, these data do show a good correlation between effluent BOD and suspended solids concentration. There are situations in which biologically inert suspended solids can be lost from an activated sludge process or when large concentrations of soluble organic matter can pass through the process. These situations are somewhat unusual.

The values of effluent BOD <20 and effluent suspended solids concentrations <30 mg/l are selected to represent the limits of what can be expected as reasonable performance from a normal activated process. The data from the effluent sample analysis which meet these limits are plotted on figure 42. These data show the general trend of an increase in effluent BOD with an increase in suspended solids concentration. However, of

TABLE XV

PERFORMANCE OF PLANTS SAMPLED

Trip No.	Influent BOD (mg/1)	Influent SS (mg/1)	Loading BOD/MLSS/t (per day)	Supernatent SS (mg/1)	Effluent SS (mg/1)	Effluent BOD (mg/1)	BOD Reduction (%)
1	189	256	0.39	64.8	95.9	> 78.3	---
2	132	174	0.44	39.4	51.4	31.5	76
3	99	142	0.084	53.1	285	13.0	87
4	46	158	0.15	47.0	240	30.7	35
5	244	136	0.30	31.8	79.8	25.7	89
6	111	198	0.16	28.6	31.3	14.4	87
7	182	110	0.16	16.3	9.0	6.3	97
8	201	69	0.082	28.2	30.3	61.8	69
9	273	178	0.78	50.8	97.7	69.5	74
10	59	50	0.18	3.6	7.7	12.5	80
11	86	62	0.015	59.1	7.1	11.2	87
12	187	276	0.044	----	2.0	10.5	94
13	94	53	0.17	32.6	30.0	11.2	88
14	406	290	0.23	218	1020	632	neg.
15	145	253	0.05	303	1880	292	neg.
16	151	96	0.29	110	93.0	72.9	52
17	519	1853	0.35	62.0	29.0	15.0	99
18	55	89	0.05	0.0	0.0	10	82
19	47	66	0.11	----	28.0	20.9	55
20	649	344	0.02	11.0	22.2	18.8	97
21	125	35	0.15	5.8	7.8	16.6	87
22	127	70	3.0	49.1	72.4	45.7	64
23	174	81	0.21	22.5	14.0	10.9	94
24	38	34	0.05	20.0	16.2	9.1	71
25	54	57	0.01	66.0	40.1	22.3	59
26	227	24	0.21	36.0	8.6	7.4	97
27	203	249	0.04	40.0	25.3	9.5	97
28	74	59	0.08	15.5	26.8	27.4	63
29	70	64	0.02	90.0	49.3	34.9	50
30	110	147	0.14	46.5	5.0	12.2	89

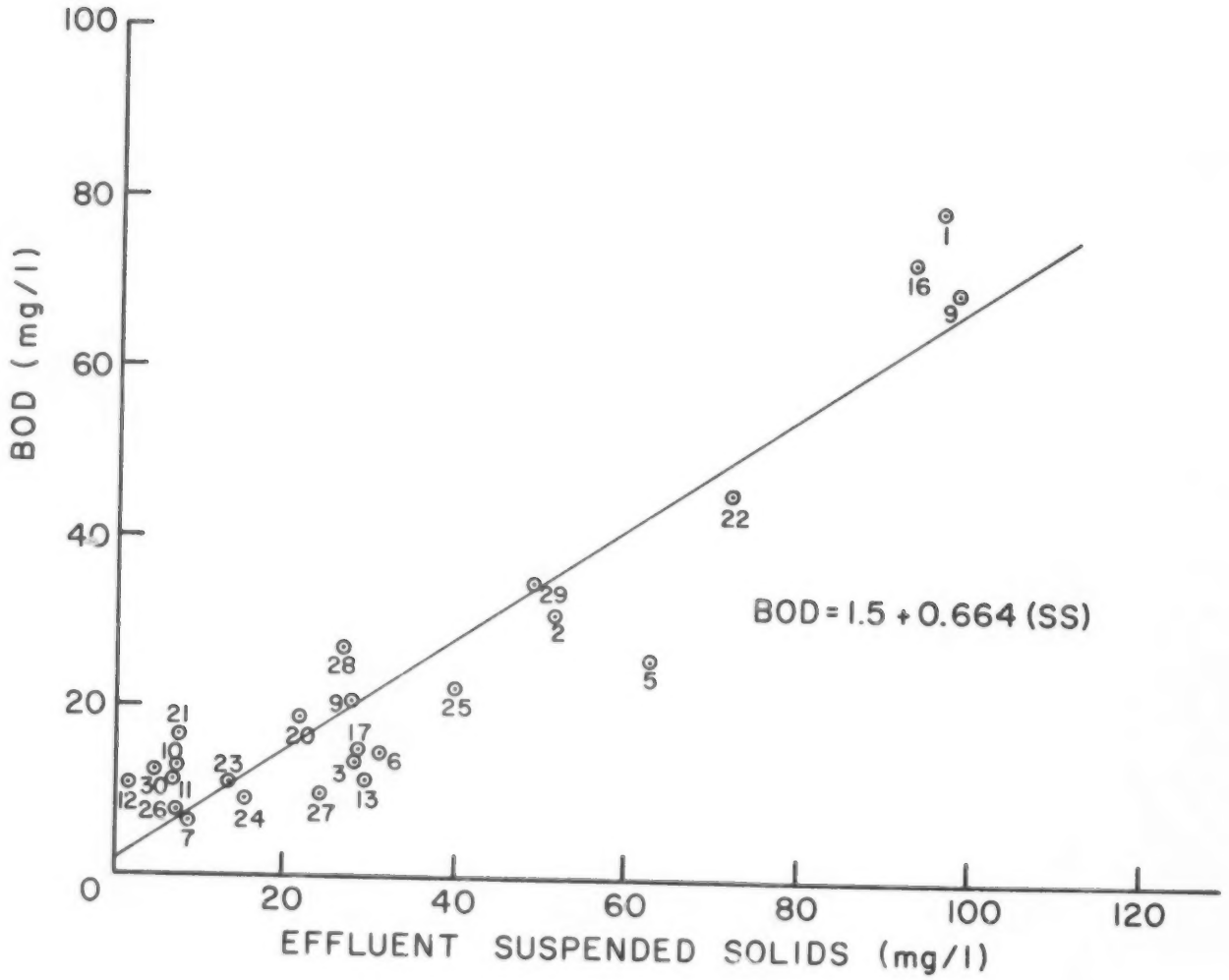

FIG. 41 - RELATIONSHIP BETWEEN EFFLUENT BOD AND EFFLUENT SUSPENDED SOLIDS

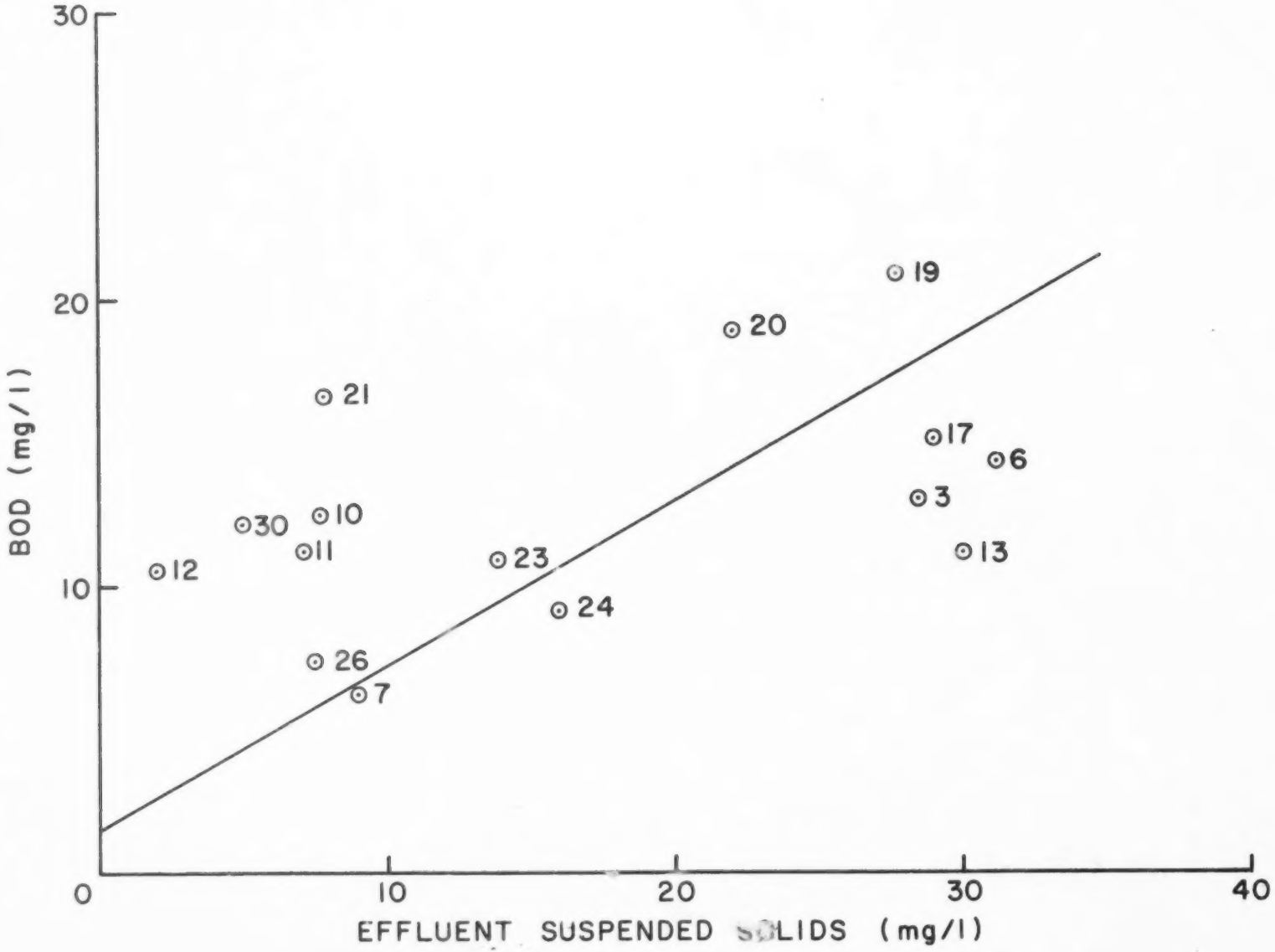

FIG. 42 - EFFLUENT BOD AND SUSPENDED SOLIDS FOR PLANTS WITH NORMAL SOLIDS LOSS

the seventeen points on the graph, only eight of them fit the equation, BOD = 1.5 + 0.664 (SS). The value of 0.664 as a proportionality between effluent BOD and suspended solids fits very well; the expected value of effluent BOD due to soluble organic matter needs to be investigated further.

Good performance from an activated sludge process requires good separation of sludge in the secondary settling tank. A bulking sludge has characteristics (low settling rate and poor compaction) which make it difficult to separate. Yet many plants with bulking sludge achieve good sludge separation. The effluent suspended solids are plotted versus the sludge volume index in figure 43. It can be seen from this figure that a high SVI usually is associated with a very low effluent suspended solids and therefore with a good quality effluent.

The effect of a high SVI is to decrease the concentration of MLSS which can be carried in the aeration tank. In figure 44 the MLSS is plotted against SVI. The samples from trips number 10, 28, 21, 18, 12, 27 and 26 fit a straight line. The plants from which these samples were obtained are operating with MLSS concentration as high as can be carried with their existing sludge compactabilities. The other samples were obtained from plants which were not pushing the solids concentration limit.

Decreasing the MLSS to too low a level can result in deflocculation. A high SVI in an activated sludge process requires reduction of MLSS and, if this is not done by the operator, solids will be lost into the effluent. Once the MLSS has been adjusted to the level which matches the sludge SVI, the process may give good results unless the MLSS is too low for the organic load. If the MLSS is too low for the organic load, then deflocculation and further solids loss occurs.

Deflocculation always results in the loss of large concentrations of suspended solids in the effluent and in a high effluent BOD. The data in table XIV indicate that the effluent suspended solids for the plants with deflocculated sludges are always higher than the suspended solids concentration in the supernatent from the settled volume determination.

Pin point floc, on the other hand, can be removed by proper operation of the secondary settling tank. In all cases where pin point floc was found, the effluent suspended solids concentration was less than or approximately equal to the supernatent suspended solids concentration.

Environmental Factors

The question of why the filamentous organisms are present as filaments which interfere with the settling and compaction of the sludge at some times and not at others is one which needs to be answered before a resolution of the bulking problem can be reached. Presumedly, some environmental factors in the aeration tank favor the growth of filamentous organisms. The identification of these environmental factors is a necessary step in the solution of the bulking problem.

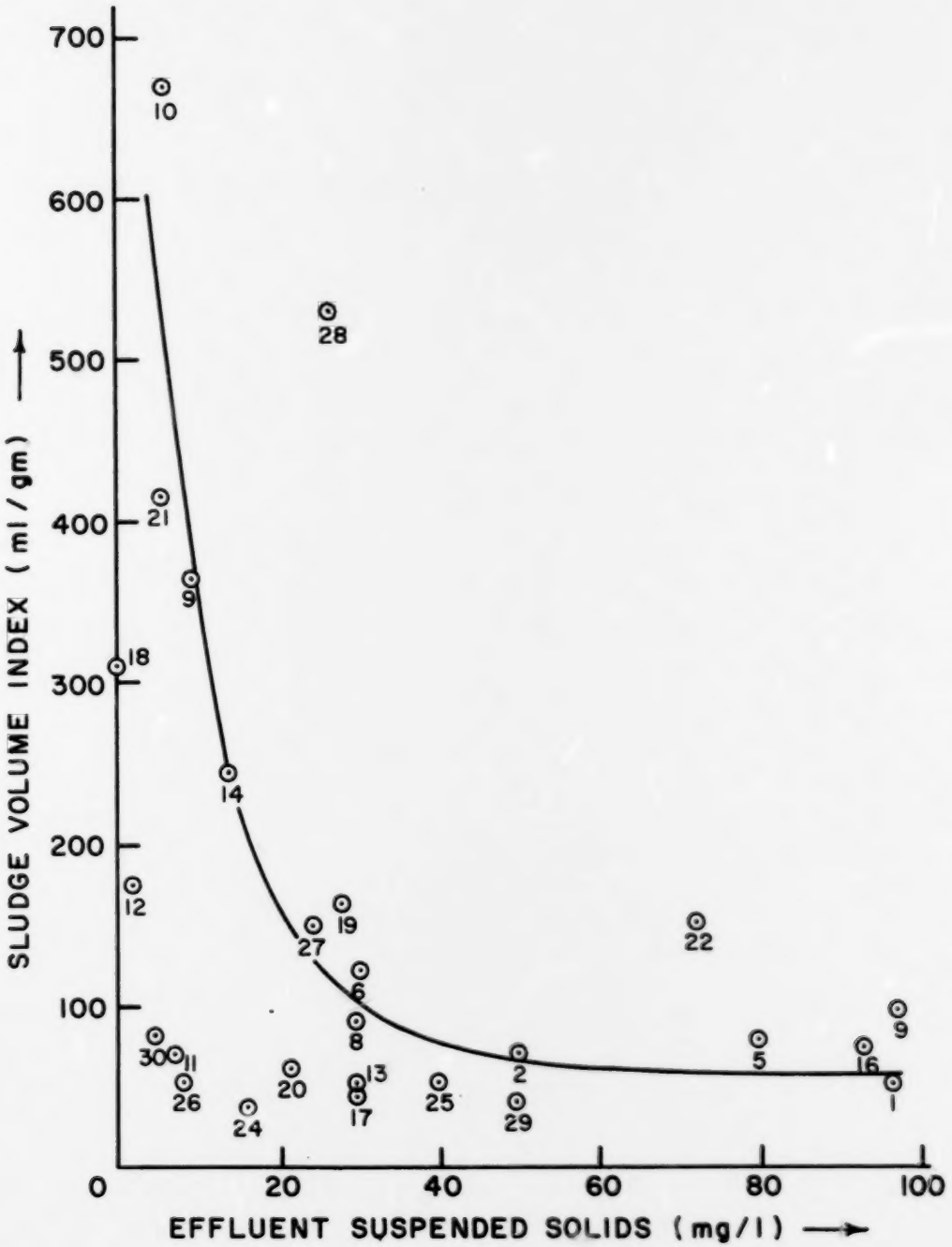

FIG. 43 - RELATIONSHIP BETWEEN SLUDGE VOLUME INDEX AND EFFLUENT SUSPENDED SOLIDS

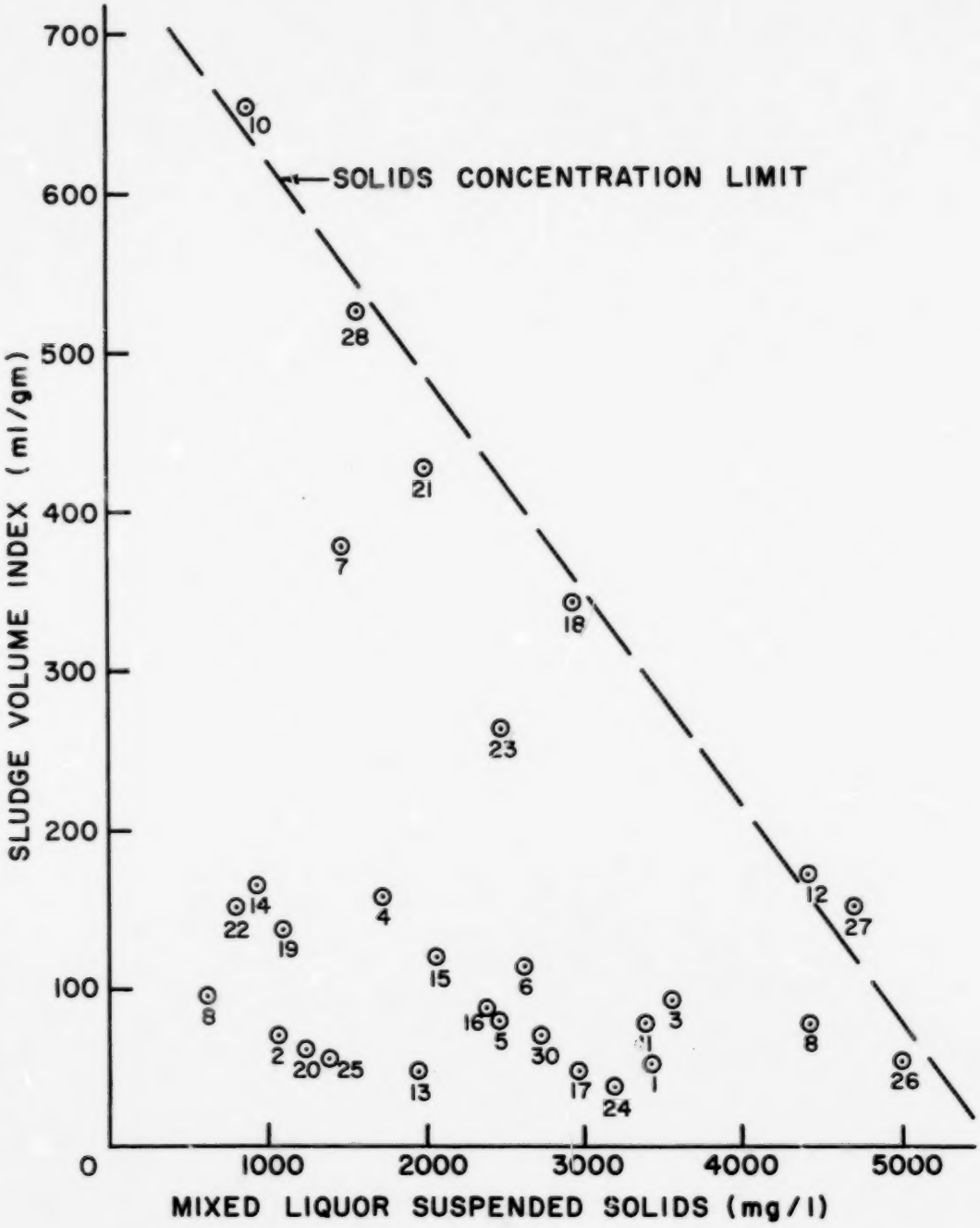

FIG. 44 - LIMIT ON MLSS BY SLUDGE COMPACTABILITY

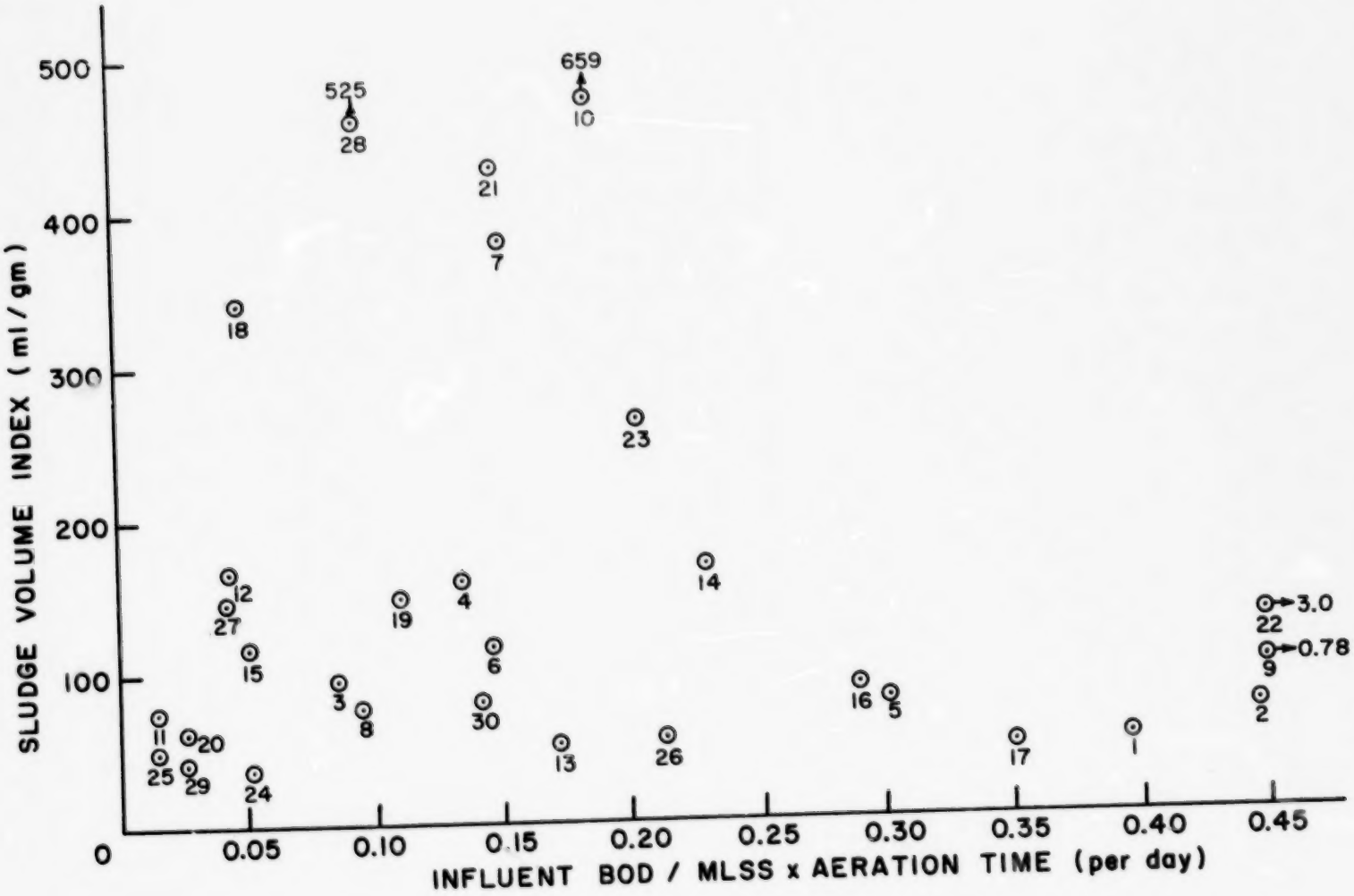

FIG. 45 - SLUDGE VOLUME INDEX AS A FUNCTION OF LOADING VELOCITY

The environmental factors which are being measured during this project include temperature, pH, dissolved oxygen concentration, concentrations of organic and ammonia nitrogen, and BOD. These data are presented in Tables XVI through XIX.

A high organic loading on the aeration tank is very often cited as the cause of a high SVI. There are several methods of calculating organic loading. For this project the ratio of the influent BOD to the MLSS divided by aeration time has been selected to represent the loading velocity. In figure 45 the SVI values are plotted against this expression of loading velocity. From this figure it can be seen that the production of a sludge with a high SVI is more likely to occur at a low loading velocity than at a high one. Thirteen of the twenty-three samples obtained from processes with a loading velocity of less than 0.2 per day had an SVI of greater than 100 ml/gm. None of the samples from plants with a loading velocity in the range 0.2 to 0.5 per day had an SVI greater than 100 ml/gm. The two cases in which the loading velocity was greater than 0.5 per day were cases of deflocculation in which the MLSS was extremely low.

The data on the environment of the aeration tanks in the cases of deflocculated sludges are summarized in Table XIX. The samples from trips number 1, 3, 4, 14, 27 and 29 all showed a dissolved oxygen concentration of less than 1.0 mg/l. The occurrence of deflocculation in these instances can be ascribed to a low D.O. The samples from trips number 5, 8 and 28 also had a D.O. of less than 1.0 mg/l. There is reason to believe that the low D.O. concentrations in these cases were the result of very short term operating difficulties. In the case of trip no. 8, the plant was receiving a dumpage of molasses from a local industry at the time of sampling. In the cases of trips number 5 and 28, the compressed air supply had been temporarily reduced at the time of sampling. Thus it appears that an activated sludge process can withstand a low D.O. for a period of a few hours, but after several hours of low D.O., deflocculation will occur.

The process sampled on trip no. 4 was the only one with a low pH. This sample contained a great many microscopic clumps of bacteria and extensive mycelial growths of fungus. The growth of the fungus in preference to bacteria is probably the result of the low pH. The deflocculated condition of the bacterial growth could be due to either low D.O. or to low pH.

As previously indicated, the cause of deflocculation in the processes sampled on trips number 9 and 22 is apparently the extremely high organic loading on the aeration tank. The deflocculation in the case of trips number 15 and 27 was due to large numbers of actinomycetes growing as small bits of mycelia.

All of the cases of deflocculated sludge encountered are explanable in terms of low D.O., low pH, excessively high organic loading, or excessive growth of actinomycetes in the processes which have no provision for sludge wasting. Deflocculation is probably the most difficult of the

TABLE XVI

AERATION TANK ENVIRONMENT

NORMAL SLUDGES

Trip No.	Plant Location	Temp. (°C.) #2	PH #2	D.O. (mg/1) #2	Organic N(mg/1)		Ammonia N(mg/1)		BOD (mg/1)		COD (mg/1)	
					Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
5	West Chicago	18	7.71	0	14.0	3.4	22.3	10.2	243.7	25.7	354	83.6
8	McHenry	16.4	7.39	0.86	4.32	2.36	6.36	4.25	201	61.8	382	158
13	Libertyville	11.4	7.69	7.6	5.37	2.84	26.7	23.4	93.7	11.2	148	33.4
20	Spinney Run F.	15.6	7.25	2.43	25.1	12.5	0.58	0	649.4	18.8	1296	101.2
24	Libertyville	15.9	7.5	7.3	2.67	0.65	2.54	3.58	37.9	9.06	40.4	39.6

TABLE XVII

AERATION TANK ENVIRONMENT

SLUDGE SAMPLES WITH PIN POINT FLOC

Trip No.	Plant Location	Temp. (°C.) #2	PH #2	D.O. (mg/l) #2	Organic N(mg/l)		Ammonia N(mg/l)		BOD (mg/l)		COD (mg/l)	
					Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
2	Crystal Lake	18.6	7.75	4.4	7.05	6.88	40.0	17.2	132.1	31.5	318	108
11	Woodstock	15.6	7.64	3.48	7.7	3.36	17.2	0.18	85.9	11.2	183	51.3
16	Antioch	6.3	7.48	5.29	10.25	8.21	13.98	16.75	150.6	72.9	310	153.2
17	N. Shore Clavey Rd.	9.4	7.76	10.1	44.0	10.48	43.0	182.2	519	15.1	2090	93.2
25	Woodstock	17.1	7.78	7.0	7.06	2.59	11.2	0.46	53.5	22.3	120.5	66.8
26	Antioch	19.8	7.56	1.48	12.3	0.93	24.3	6.59	227.4	7.4	400	33.6
30	Chicago, N. Side	23	7.0	3.44	6.65	1.13	12.37	7.37	110	12.2	212.2	28.6

TABLE XVIII

AERATION TANK ENVIRONMENT

BULKING SLUDGES

Trip No.	Plant Location	Temp. (°C.) #2	PH #2	D.O. (mg/l) #2	Organic N(mg/l)		Ammonia N(mg/l)		BOD (mg/l)		COD (mg/l)	
					Inf. (6)	Eff. (5)	Inf. (6)or(7)	Eff. (5)	Inf. 6	Eff. 5	Inf. 6	Eff. 5
6	Chicago, N. Side	20.2	7.38	2.65	4.82	1.07	5.81	6.85	110.6	14.4	737	76.4
7	Ft. Wayne	19.6	7.05	2.64	6.71	0.60	11.0	0.34	181.6	6.3	336	30.9
10	Brookfield	13.3	7.63	3.50	4.91	1.32	15.4	16.67	58.7	12.5	107.4	43.8
12	Gages Lake	11.8	6.98	2.57	22.9	3.87	25.2	1.54	187	10.5	369	39.3
18	Gary	10.7	7.68	0.31	6.48	4.74	31.4	48.9	54.7	10.0	214.2	64.8
19	Brookfield	8.1	7.58	8.8	6.18	1.88	5.75	2.6	47.0	20.9	72.4	25.8
21	Ft. Wayne	14.9	7.52	1.25	6.95	1.5	11.10	4.31	125	16.6	292	53.2
23	West Chicago	14.5	7.55	4.1	9.53	0.9	14.61	2.88	173.5	10.9	253	51
28	McHenry	18.4	7.3	0.68	6.58	2.88	10.03	5.32	74.3	27.4	141.3	61

TABLE XIX

AERATION TANK ENVIRONMENT

DEFLOCCULATED SLUDGES

Trip No.	Plant Location	Temp. (°C.)	PH	D.O. (mg/l)	Organic N(mg/l)		Ammonia N(mg/l)		BOD (mg/l)		COD (mg/l)	
					Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	Carol Stream	19.0	6.80	0	7.0	8.7	15.3	6.5	189.4	>78.3	553	333
3	West Chicago	19.0	7.7	0	10.45	1.37	18.49	7.78	98.7	13.0	201.9	42.7
4	Fox River Grove	15.8	3.41	0	14.3	10.8	26.6	16.9	46.0	30.7	138	174
9	Milton	15.0	7.82	5.91	15.6	7.86	44.65	33.70	273	69.5	387.5	167.2
14	Spinney Run F.	14	6.7	0.9	19.67	68.7	2.59	3.67	406	632	816	1325
15	Borden's Dairy	27.3	7.78	3.8	27.5	61.4	1.44	0.5	145	292	1127	2512
22	Milton	13	7.3	6.08	13.4	7.68	24.8	25.8	126.7	45.7	212.3	147.5
27	Gages Lake	18.8	7.45	0.5	20.4	3.51	39.2	8.5	203.5	9.5	414	66.8
29	Gary	20.6	7.17	0.2	5.69	3.9	4.13	4.5	70	34.9	187.2	114

operating problems in terms of preventing sludge loss when it is occuring. However, in all cases of deflocculation there is an apparent cause and therefore an apparent cure.

There is not any apparent cause for any of the cases of bulking from a survey of the data in Table XVIII. The one case of Sphaerotilus bulking (trip 28) was associated with a low D.O., but this was a temporary condition in the plant. The five cases of Bacillus bulking (trips 7, 18, 19, 21, 23) were associated with environmental conditions which appeared to be entirely normal. The aeration tank environment in the other three cases of bulking also appears to be entirely normal.

In all of the cases in which pin point floc was found, the D.O. concentration was relatively high. This could be an indication that the high D.O. and pin point floc are both the result of the same factor; i.e., excessive turbulence due to more than adequate air supply. There is also some indication that pin point floc may be associated with lower temperatures in the aeration tank.

Bulking of activated sludge (high sludge volume index) has been blamed on many different environmental factors including excessive organic loading, excessive soluble BOD in the form of carbohydrates, low D.O., low pH, etc. From the data being collected on this project, it is apparent that these environmental factors are a direct cause of deflocculation rather than bulking.

Bulking is a complex of several phenomena which have a few features in common; namely, excessive growths of filamentous organisms in the sludge, low settling rate of the sludge, and poor compactability of the sludge. The low settling rate and poor compactability of the sludge makes it difficult to separate in the secondary settling tank and return to the aeration tank in adequate quantities to treat the influent waste. However, a plant with adequate capacity in the secondary settling tank and the return sludge pumps and lines can operate with a bulking sludge and produce a very good quality effluent.

When a high sludge volume index occurs in an activated sludge process which does not have adequate sedimentation and return sludge capacity, the mixed liquor suspended solids must be reduced. Either the MLSS will be reduced by the plant operator or the sludge solids will fill up the secondary settling tank and overflow into the effluent. The reduction in MLSS, if it is carried to an extreme, can result in deflocculation due to excessive organic loading.

SUMMARY

This is an interim report on an attempt to describe some of the types of problems which interfere with the operation of the activated sludge process and determine the biological nature of these problems. These operating problems are manifest by poor separation of sludge in the secondary settling tank, loss of sludge in the effluent, and high effluent BOD due to the respiratory activities of sludge organisms. Previously, all of these problems have been called "bulking" at one time or another. The development of solutions to these problems requires that each of the problems be described in terms of the associated phenomena in the aeration tank and in the settling tank, and that there be a clear distinction between the various problems.

The particular problems which are being studied are bulking sludge, pin point floc, and deflocculation. Rising sludge, septic sludge, overaerated sludge, floating sludge, and billowing sludge have been encountered during the sampling program, but are not being investigated as a part of this project.

A normal sludge is defined as one which will settle rapidly in a 1000 ml graduated cylinder to give a SVI of less than 100 ml/gm, and leave a supernatent with less than 30 mg/l suspended solids. If the supernatent suspended solids are greater than 30 mg/l, the sludge is either deflocculated or producing pin point floc. Pin point floc is recognized as discrete particles suspended in a clear supernatent. Deflocculation of the sludge produces a very turbid supernatent.

A bulking sludge is defined as one which has a sludge volume index of greater than 100 ml/gm and produces a supernatent with a suspended solids concentration of less than 30 mg/l. A sludge volume index in the range of 100-300 ml/gm is considered to indicate moderate bulking, while a sludge volume index of greater than 100 ml/gm is severe bulking. A bulking sludge always produces a very clear supernatent with a low concentration of suspended solids.

In certain types of deflocculation, the SVI of the sludge which settles is greater than 100 ml/gm. However, the primary sludge separation problem in these cases is the suspended solids which do not settle rather than the high SVI of the sludge which does settle. Many activated sludge processes can be operated with no sludge loss into the effluent when the SVI is greater than 100 mg/l, but there is no way of separating the very fine particles of deflocculated sludge.

Of the thirty sets of samples which were collected to supply the data for this report, four are classified as normal sludge, nine as bulking sludge, nine as deflocculated, and eight as having pin point floc. Since the initial plant selection was made on the basis of obtaining samples from plants which have operating problems, the proportion of normal sludge samples is undoubtedly low, but it is apparent that operating problems with the activated sludge process are very common.

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Microscopic counting and sizing of sludge particles and filaments produced data which shows that there is no direct relationship between particle size and settling characteristics of the sludge. However, it is demonstrated that the sludge volume index of a sludge sample is directly proportional to the number of filaments in the sludge.

Several different filamentous organisms are found to be present in bulking sludges. Of the nine bulking sludge examined, filamentous members of the genus Bacillus was found to be the most significant filamentous organism in five cases, Sphaerotilus in one case, Beggiatoa in one case, actinomycetes in one case, and in one case the filamentous bacterium has not yet been identified. The judgment of the most significant filamentous organism in the sludge is based on prevalence of the organisms on streak and pour plates, and on morphological similarity between the organisms in pure culture and in the sludge sample.

All of the samples examined were found to contain fungi which reproduce by production of either arthrospores of blastospores or both. This group of organisms, including species of Geotrichum, Trichosporon, Candida, and Rhodotorula, is described as sludge yeasts. A proportionality between the SVI and the count of sludge yeasts on pour plates is demonstrated for fifteen samples. The samples which do not fit this relationship are those having large numbers of filamentous bacteria.

No particular relationship between any environmental factor and any of the types of bulking is demonstrated. All of the cases of bulking are associated with low organic loading (< 0.25 per day) on the aeration tank. Several of the conditions previously described as causing bulking are associated with deflocculation. The conditions are low D.O., low pH, and high organic loading (> 0.5 per day). Bulking can lead to deflocculation if the SVI becomes so high that the MLSS must be reduced to the point at which the organic loading becomes excessive.

Pin point floc is only produced when the sludge in the process has a low sludge volume index. There is an indication that the production of pin point floc is favored by low temperature and high dissolved oxygen concentration.

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